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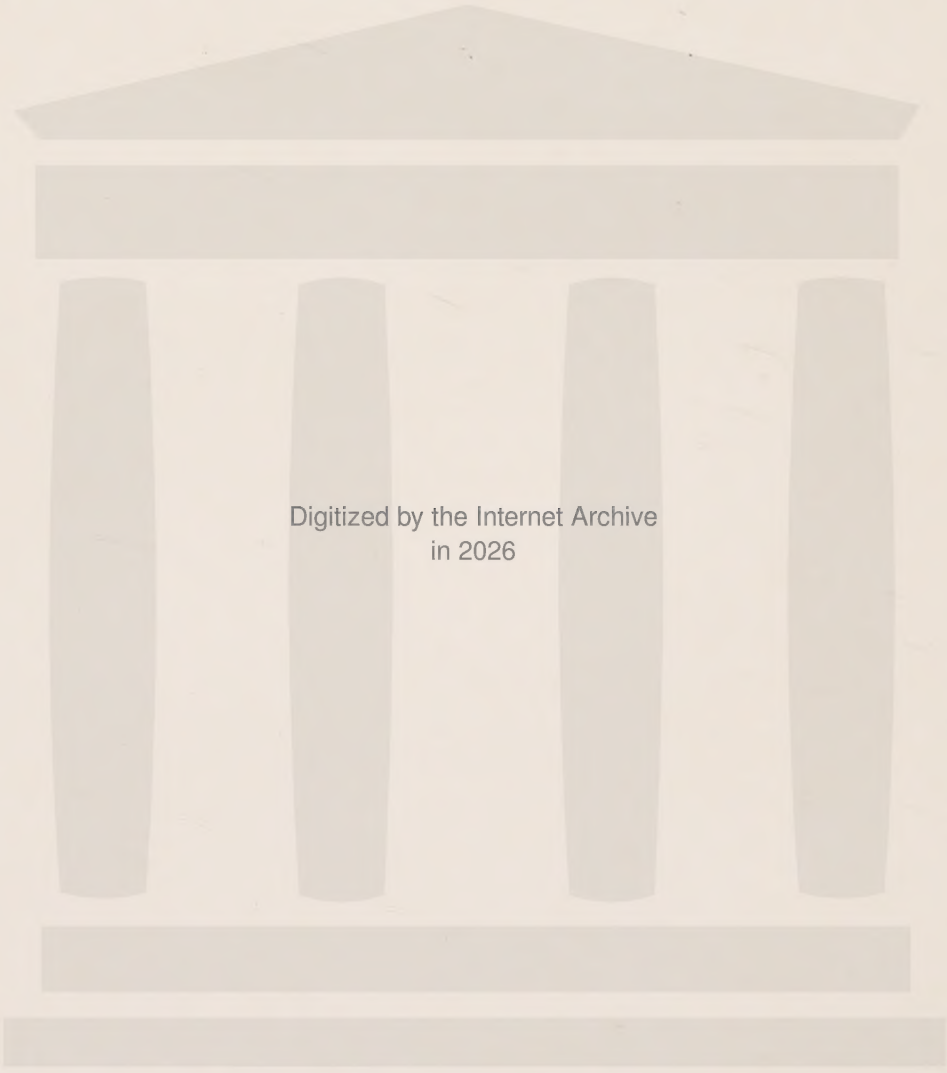

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Republic of South Africa
Department of Environmental Affairs and Tourism
MARINE & COASTAL MANAGEMENT

RESEARCH HIGHLIGHTS 1998•1999

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An annual publication reporting on research of the past calendar year together with a preview of some to be undertaken

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MISSION OF
MARINE & COASTAL MANAGEMENT

To provide for the responsible custodianship of South Africa's marine and coastal resources and ecosystems for the benefit of current and future generations of South African's. This is achieved by the conservation of such resources and ecosystems through the control of, and the orderly, fair, and equitable access to, their optimum sustainable utilisation. Activities are undertaken in accordance with national and international norms, and are

- carried out under the auspices of the Department of Environmental Affairs and Tourism in an open, cooperative and accountable manner, subject to Government policy, and
- based on rigorous, multidisciplinary research and monitoring aimed at developing a comprehensive understanding of relevant resources and ecosystems as well as of relevant industries and communities.

INTRODUCTION

Those who read annual departmental research reviews in the discipline of marine science will have noted the various cautions I expressed in my introduction last year. Some, such as the shrinking funding base and the need to make the research community more representative of the country's demography, have indeed been in evidence this year. It is therefore gratifying to be able to say that, in the last year, researchers have risen to the challenge of doing even better with less funding and that many have become extensively involved in the capacity-building, training initiatives essential to ensuring that the second challenge does not remain simply a pipedream. More of those two issues later, however. The overriding change that government has made this year, one that has a profound effect on the research echelon in particular, has been to seek a greater integration of science, resource control and regulation in the overall fisheries management field. Scientists have always been willing to assist in general fisheries management in South Africa, as in other parts of the world, but in the inferred words of a senior government official when opening a major international fisheries symposium in Cape Town at the end of 1998, they must become more involved in implementing and defending the outcome of their advice and not simply hide behind the veneer of unbiased scientific integrity. Of course, that does not mean that the same scientists involved in determining levels of annual catch should have a major say in who gets what. It simply means that they should take their advice to the next stage, that of implementing the decisions of those involved in allocating access rights, in determining the impact of those decisions, and more importantly in being involved in an advisory rather than a decision-making way in the decisions themselves.

The above is a philosophical debate, however. The real issue is what has it meant to South African government marine scientists? Well, it has meant a great deal. First and foremost, the policy decision was made by government that research was generally not its line function *per se*, though facilitating it was. The second decision, this time by the department and supported by Sea Fisheries itself, was that, for the next few years at least, the best way to allow the objectives of Sea Fisheries to be met would be to find ways to integrate more fully the various functional groups of marine fisheries management, namely, research, control and general administration. Implementation of that decision meant that the former Sea Fisheries Research Institute (which was simply the research arm of the Chief Directorate Sea Fisheries), lost its identity though not its general aims. In October 1998, therefore, the Institute name was consigned to history and the researchers reverted simply to their ongoing role as government officials. The next step was to find a way, by means of structural re-engineering, to make Sea Fisheries better able to deliver quality service and to meet its other challenges for the next millenium. A key philosophy in that aim was the obvious one of bringing those responsible for management of and development in the coastal fringe into the same State harness. Out of that alignment was born the new Chief Directorate Marine & Coastal Management. Future research reports such as this will therefore give a synthesis of what that component has done over the previous year, although virtually all its research has traditionally been outsourced, as indeed is some of the marine component's.

Another decision of far-reaching implication in the re-engineering process was to bring offshore research, regulation and control into a single directorate, the same components of coastal and inshore management into another, and to develop a new directorate for the crucial need to develop fisheries and to improve the rigour of social and economic data and analysis. Consequently, the Chief Directorate Marine & Coastal Management now has four directorates, one

dealing (as previously) with predominantly staff support functions, communications and IT and the fleet, two dealing with respectively offshore, and coastal and inshore, resources management, and the final one dealing with economics and resource development. The former directors of research and control matters took up the two resource management portfolios and, together with the future appointee to the post of director of economics and resource development, will jointly bear the responsibility for preparation of this annual research report; it is in those three directorates that all the old research posts of the Sea Fisheries Research Institute now resort. One major challenge will, of course, be to find a workable manner for researchers in the three new directorates to interact without allowing overlap of functions and disciplines to interfere. As an organization that embraced a matrix system of interdisciplinary operation some years ago, that is a challenge that the former research component are eagerly looking forward to meeting, no doubt with success.

The above is a structural analysis, but it is embedded in an ongoing excellence of research output from the organization that the following pages put into perspective. The reader is reminded that the major change of structural alignment took place only from October 1998 onwards. The overall layout of this publication therefore follows that of its predecessors; future layout may or may not, depending on how the research output focuses in future, change. It must be stressed too that most of the research done is being carried out by exactly the same personnel (allowing for natural attrition and change, neither of which have accelerated) as before. Perhaps future priority focus for individual scientists as well as for the organization as a whole may change (as it has over the years before), but the general disciplinary thrusts will have to remain; one should not change a winning formula. Even contracted marine scientists are largely the same as in the past, though it is likely that outsourcing of social and economic research to improve inputs to fisheries management will bring a new perspective to the contents of this publication in future. Similarly, official recognition of the rights of subsistence fisheries to exist along with the commercial and recreational ones has also brought a new band of qualified research personnel into contractual agreements with Marine & Coastal Management. Some of this outsourcing and even some traditional contractual relationships are being supported by welcome funding initiatives from other countries, notably those in Europe. Indeed, as reported last year, donor funding (especially where it brings the valuable adjunct of capacity building) now plays a large role in marine and coastal research as well as management. Regional initiatives, as mentioned last year, are also well serviced from similar sources (see the section on international engagements), and a major source of funding for all aspects of marine fisheries management (not just research) has come from the new Marine Living Resources Fund. In the financial year 1999/2000 alone, research and the research fleet alone was supported from that fund to the extent of about R10 million (almost US$2 million).

Each issue of this publication seems bent on outdoing its predecessor. Perhaps one reason for that is the change in editor, almost annually! Certainly, this year's editor is the third in three successive years. However, another key to the improvement from year to year has obviously been the wish of researchers to do even better than they did in the past. Support from administrators in achieving that goal is, of course, crucial, and the support of the politicians and other senior advisors to the decision-making process in South Africa is almost legendary. I am therefore confident that what follows is a real reflection of an ongoing pursuit of scientific excellence, particularly, not entirely, in the discipline of science applied to fisheries management. I am equally confident that the results of the traditionally misnamed "academic" research in this organization will continue to become even more relevant in an applied nature, in other words that all the output will eventually have to be categorized "have to know" rather than a mix of "nice to know" and straight fisheries assessment results.

I am annually criticized for lifting out highlights of research highlights, but I genuinely believe that an introduction to such a publication as this cannot be written without mentioning a few real highpoints. Therefore, I must mention the importance to South Africa of the ecosystem modelling that is now starting to show why our dynamic system and its components have changed over the past few decades; the seaweed culture work that is allowing potential entrepreneurs to find other resources on which to stake their livelihood (the research aquarium facility will help develop that and other experimental research in future); the modelling work on chokka squid *Loligo vulgaris reynaudii* that essentially led to a testable hypothesis on how the jig fishery had been impacting the resource on which it depended; the work on the relationship between harmful algal blooms and the ecosystem in which they have become an apparently increasing phenomenon; and the ongoing development of operational management procedures for many South African fisheries (South Africa is clearly still a world leader in that discipline). I could continue, but instead I will refer the reader to the pages that follow. My colleagues and I can promise more and better in future if the past few months are anything to go by. However, I would be remiss were I not to refer to the efforts of the editors of the two international symposium volumes that were released since this time last year – that on the Benguela Ecology Programme known simply as *Benguela Dynamics*, and the other on the outcome of the world cephalopod conference run in Cape Town for CIAC. Both were published in-house, and another volume, on the 1998 ICES fisheries management conference, is expected to be published in the ICES series before the end of 1999.

In finishing, I must reiterate my optimism for the future. The research work being carried out is high quality, the personnel (in-house and contractual) are of the top echelon worldwide, and despite the financial squeeze on science all over the world, there is much to be thankful for that our donors and the administrators of the Marine Living Resources Fund put their money and their confidence in personnel and science in South Africa. Finally, the first batch of trainee marine scientists supported by foreign funds at overseas academic institutions is soon to return to make their anticipated mark in local marine and fisheries science along with their peers trained locally in institutions internationally recognized for their excellence in teaching and research. That bodes well for the future of marine research in South Africa.

Pelagic fish

Operational Management Procedures (OMPs) are considered an important management tool for South African fisheries and are the subject of ongoing research, particularly for the small pelagic, hake and rock lobster fisheries. In the pelagic context, an OMP is simply a set of relatively simple formulae that convert the biomass estimates obtained from annual hydroacoustic surveys into *TAC* recommendations. The process of selecting an OMP is based on computer simulations whereby an underlying model (the "true" model, conditioned on past data) simulates "reality" over a 20-year time horizon. Candidate OMPs are tested by deriving *TACs* using these simulated data (Fig. 1). OMPs are selected on the basis of longer term considerations: ensuring catches that are as high as possible over a period of time, while simultaneously not exposing resources to undue risk of depletion to unproductive levels. Ideally, excessive variations in *TAC* from one year to the next must be avoided. Once selected, the OMP is applied to real data and is used to provide the *TAC* used for actual recommendations. A range of OMP candidates was presented to Marine & Coastal Management's Consultative Advisory Forum (CAF) early in the 1999 pelagic fishing season and, after long deliberations, a choice was made. The species *TACs* and the sardine *Sardinop sagax* by-catch allowance were readily computed thereafter, on the basis of the results from the November scientific survey.

The anchovy *Engraulis capensis* fishery has been regulated by management procedures since the late 1980s, and in 1994 these procedures were expanded to include sardine as well. The reason for the two fisheries being considered jointly is that some juvenile sardine bycatch is inevitable in the anchovy fishery because shoals of the two species mix. Therefore, the more anchovy taken, the greater the juvenile sardine bycatch, and

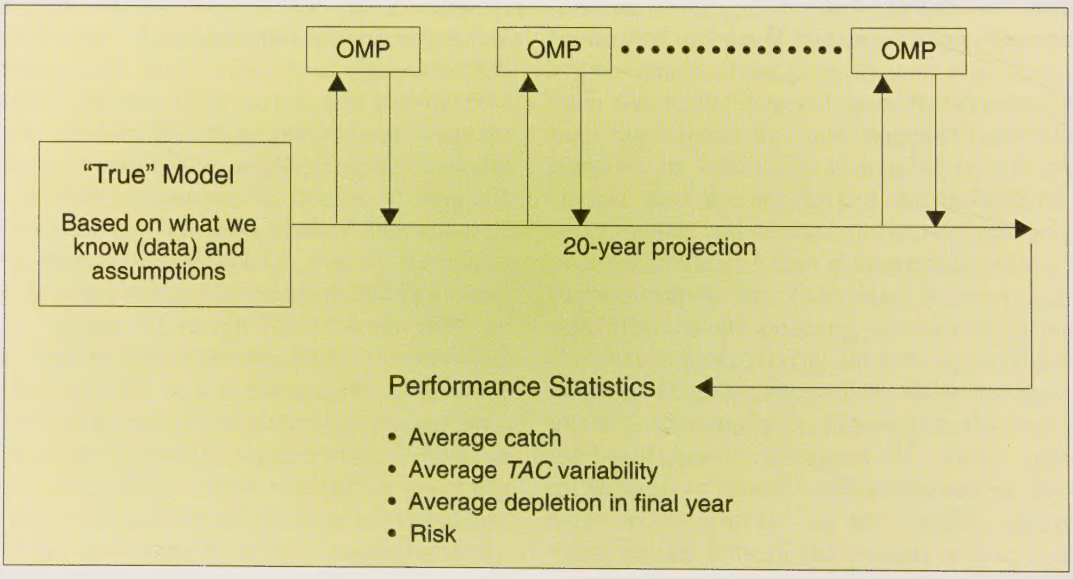

Fig. 1: A schematic diagram of the process for testing a candidate OMP. The OMP boxes indicate that the OMP sets annual TACs based on simulated future data from the "true" model

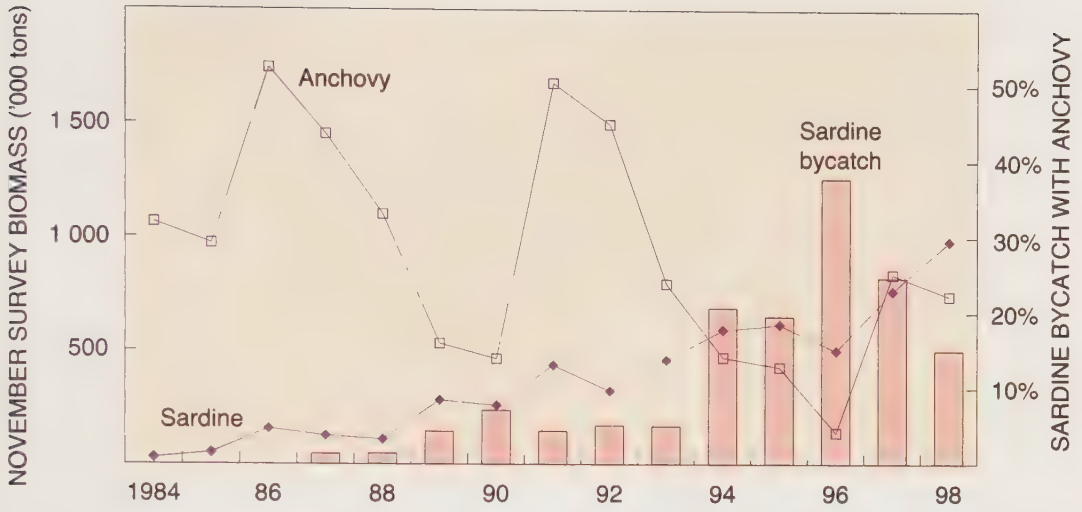

Fig. 2: Estimates of sardine and anchovy adult biomass from November hydroacoustic surveys (dotted and solid lines respectively), and sardine bycatch as a percentage of the anchovy catch in commercial landings that comprise more than 50% anchovy (bars)

consequently the lesser directed catch of adult sardine that can be allowed. It is impossible to choose an OMP that will simultaneously maximize sardine-directed and anchovy-directed catches, and a sardine-anchovy trade-off is fundamental in any OMP considered for this mixed-species fishery.

It is customary to consider revision of OMP formulae every few years, in the light of improved scientific understanding, further data becoming available since the time of the previous revision, and practical experiences in implementing the last revision. A particular problem with the formulae developed in 1994 was that it made inadequate allowance for juvenile sardine bycatch in recent years. Sardine abundance has grown over the past five years, so the proportion of juvenile sardine caught with anchovy has increased (Fig. 2). An important new feature of the OMP is the use of both the sardine/anchovy ratio measured in the commercial fishery during May and that determined during the May recruitment survey in the midyear adjustment of the sardine bycatch allowance. This should ensure that this allowance proves more realistic for the smooth operation of the fishery than was at times the case in the past. However, the more flexible approach to sardine bycatch, coupled with the sardine-anchovy trade-off fundamental to the fishery, means that, if a reasonable level of sardine-directed catch is required, the anchovy catch will have to be kept low, leading to underutilization of the anchovy resource. Possible solutions to this problem are currently being investigated together with more flexible management options within the OMP framework.

Regular monitoring of the pelagic resources continued during 1998 and 1999. Anchovy recruitment measured during June 1998 was slightly higher than that measured in the previous year (Fig. 3a). This indicated substantial recruitment for a second consecutive year and the prognosis of a reasonable adult population by the end of 1998. It is apparent that, while anchovy seems to have partially recovered from the all-time-low 1996 recruitment failure, sardine continues the pattern emerging over the past six years of alternating good and poor recruitment (Fig. 3b). Of interest is the fact that, for the first time in the past six years, both species have different recruitment trends.

The 15th annual spawner biomass survey took

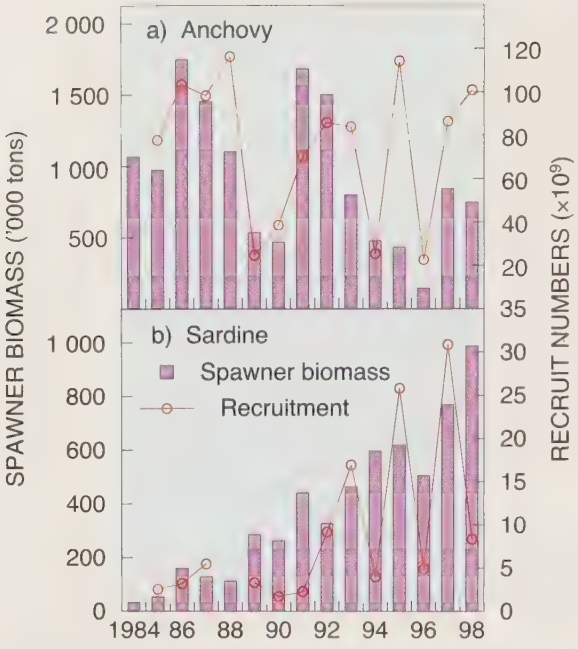

Fig. 3: Time series of mid-year recruitment and end-of-year spawner biomass for anchovy (a) and sardine (b)

place in November 1998. While anchovy biomass remained virtually unchanged from that measured during 1997 (Fig. 3a), the biomass of sardine was the highest since the start of the present time-series (Fig. 3b). The anchovy estimate was lower than expected following the results from the recruitment survey in June. It is becoming apparent that the mortality of recruits may be size-dependent. As the large recruitment of anchovy was dominated by small fish (< 7 cm), these may not have survived to the end of the year. The increase in sardine biomass took place, however, despite the low recruitment measured earlier in the year.

Anchovy were distributed mainly on the outer shelf between Cape Agulhas and Plettenberg Bay, with isolated patches on the western Agulhas Bank and near Port Elizabeth (Fig. 4). Surprisingly, the former were often found inside bays, as opposed to anchovy's traditional midshelf distribution pattern at that time of the year. Records of anchovy off Port Elizabeth were also unexpected; no substantial densities of anchovy are normally found there. Pockets of sardine were observed off Cape Columbine and up the West Coast, but the largest proportion of the sardine population was concentrated inshore between Cape Hangklip and Cape Infanta and over the midshelf off Mossel Bay (Fig. 5).

Of concern was the absence of anchovy eggs on the traditional spawning grounds west of Mossel Bay. Whether this reflected spawning failure or a delay in the spawning process still has to be ascertained. A delay in the spawning

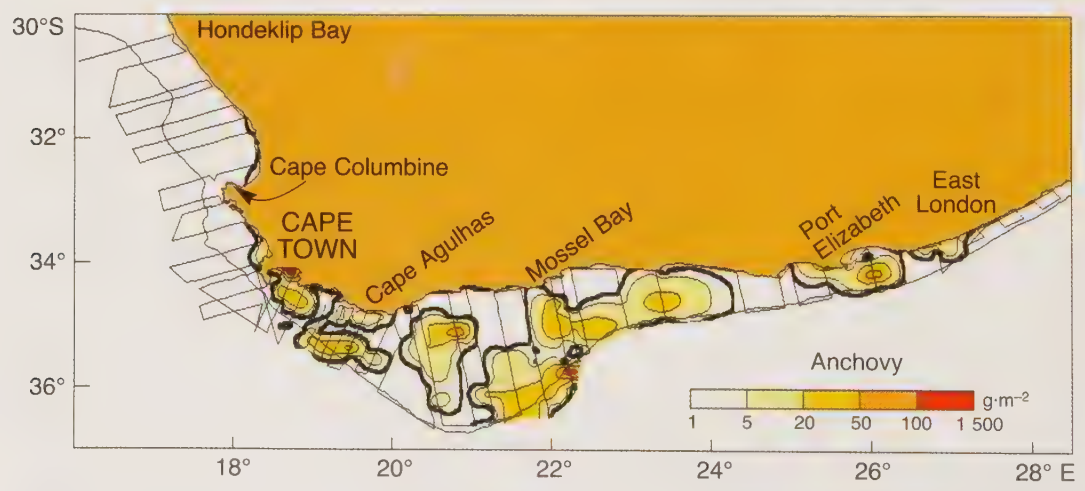

Fig. 4: Distribution and relative abundance of anchovy during the 1998 Pelagic Spawner Biomass survey

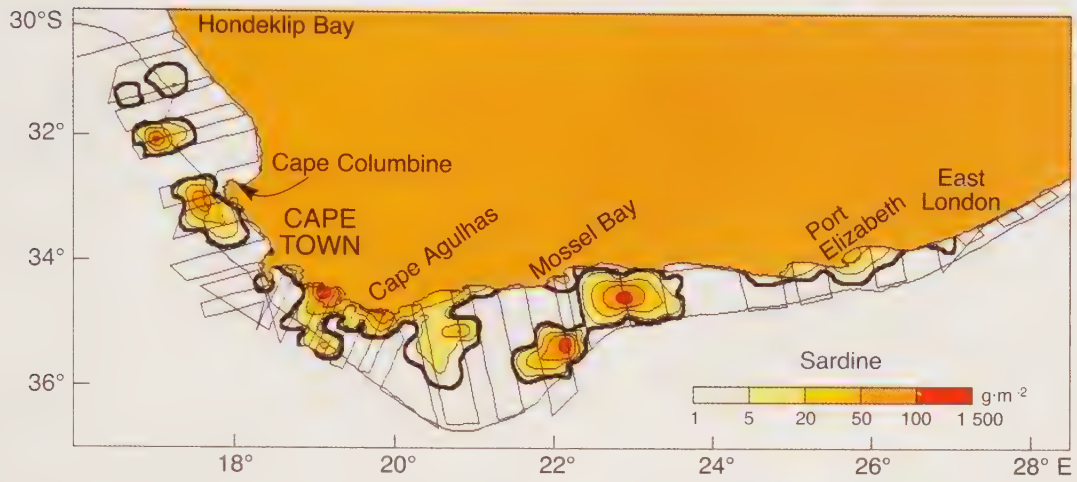

Fig. 5: Distribution and relative abundance of sardine during the 1998 Pelagic Spawner Biomass survey

process would produce undersized anchovy recruits, more prone to natural mortality, in 1999. Conversely, the extensive distribution of sardine eggs onto the West Coast was reminiscent of times when the sardine resource was the main pelagic fishery. The prospect for sardine recruitment during 1999 is therefore optimistic.

Results from the March 1999 pelagic pre-recruit survey showed that anchovy pre-recruits were more abundant than has been observed during recent years, with the mean density being the third highest of the time-series and comparable to the estimates obtained for 1991 and 1992 (Fig. 6). As is generally the case, anchovy pre-recruits were distributed over the entire West Coast nursery area, and were found in 97% of samples collected. They showed marked cross-shelf gradients in their distribution according to size, the smallest fish being found offshore and progressively larger fish being found inshore. In contrast to anchovy, both mean density and the percentage occurrence of sardine pre-recruits were lower than those observed during the past five years (Fig. 6).

During 1998, a comprehensive analysis of the pre-recruit survey data was undertaken in order to assess whether the pre-recruit abundance index timeseries could be used to predict recruitment. Whereas no relationship could be derived between mean anchovy pre-recruit density and subsequent recruitment strength as measured during the May/June recruit survey (Fig. 7a), mean pre-

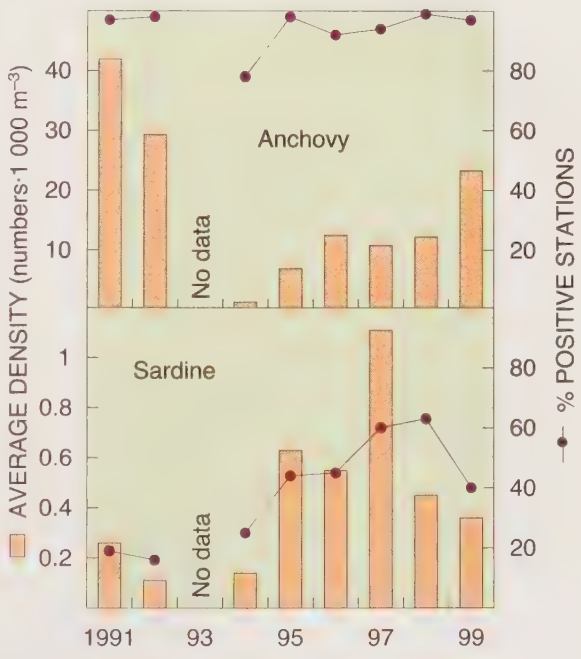

Fig. 6: Time-series of the abundance index (mean density in number·1000m⁻³) and frequency of occurrence (% positive stations) for anchovy and sardine pre-recruits on the West Coast north of Cape Columbine, 1991–1999

recruit density was significantly related to recruitment as estimated using the anchovy population assessment model (Fig. 7b). This model uses data from the recruit and spawner biomass surveys, and incorporates catch data, to estimate anchovy recruitment at the beginning of the year. Applying the relationship to the 1999 anchovy pre-recruit data gives an estimated year-beginning recruitment of 330 billion, a value above the long-term average of 260 billion begin-year recruits. A significant relationship between mean pre-recruit density and subsequent recruitment strength measured during the May/June recruit survey was obtained for sardine (Fig. 7c). This relationship must be viewed with caution however, because its validity is strongly dependent on the data points for 1995

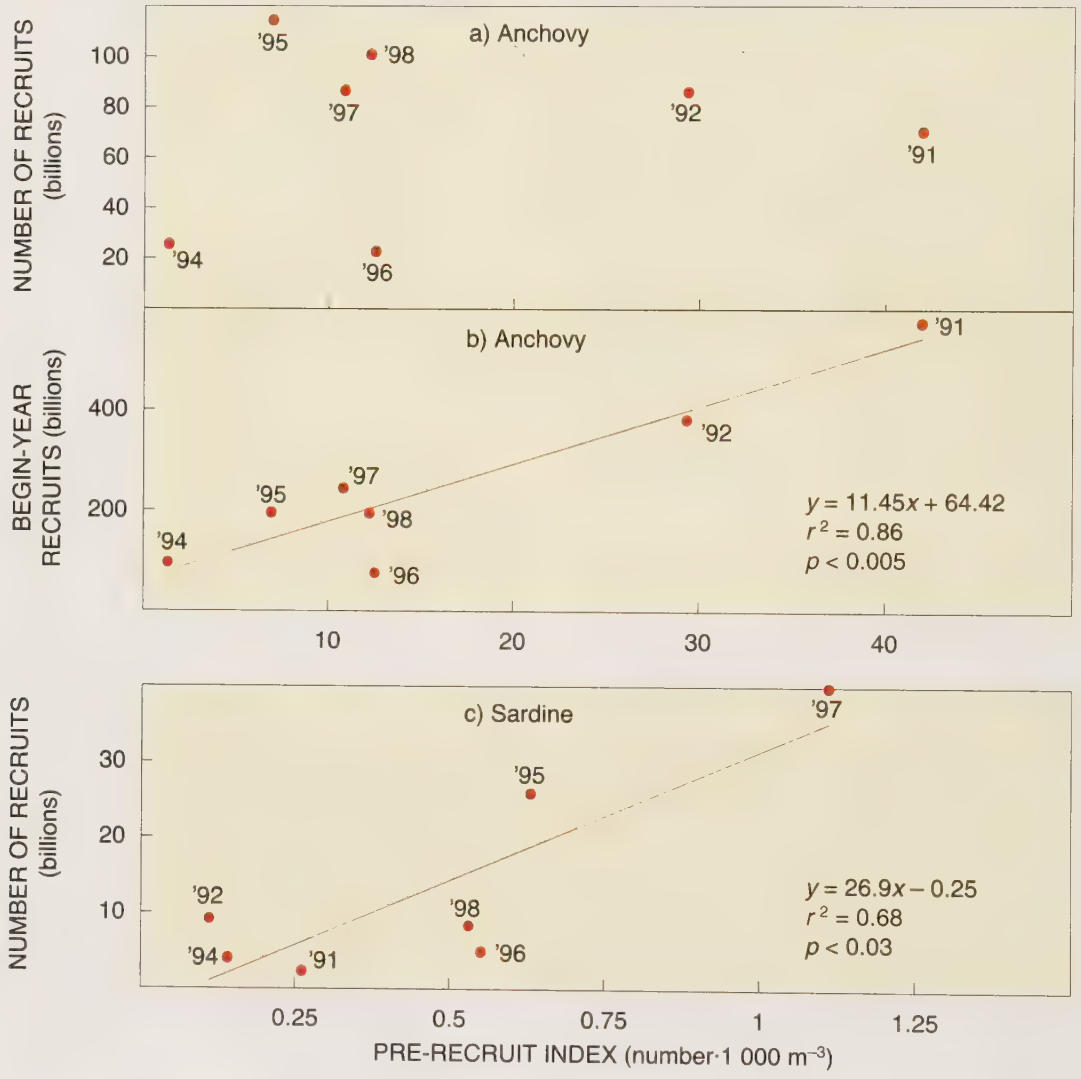

Fig. 7: Scatterplots of the pre-recruit abundance index (number·1000m^{-3}) and (a) subsequent anchovy recruitment as estimated by the recruit survey, (b) begin-year anchovy recruitment as estimated by the anchovy assessment model, and (c) subsequent sardine recruitment as estimated by the recruit survey. The data points have been labeled by year, and linear regressions have been fitted for (b) and (c), with the regression parameters shown on the graphs

and 1997: years where a high pre-recruit mean density was followed by excellent recruitment. Applying this relationship to the 1999 survey data gives a predicted recruitment strength of approximately 9 billion sardine recruits, similar to sardine recruitment estimated for 1998.

Further development of the pre-recruit abundance indices, where abundance is weighted according to size with larger pre-recruits contributing more to the index than small ones, is currently under way. Although this method shows some promise as a tool for predicting recruitment, a rigorous analysis incorporating estimates of natural mortality and taking into account the likelihood of larger pre-recruits avoiding the sampling nets, has yet to be completed. Environmental data collected during the pre-recruit surveys may also be factored into the pre-recruit abundance indices. For example, surveys during which a high proportion of anchovy pre-recruits was found in water where the sea surface temperature was >17°C have tended to be years of above-average recruitment. Future pre-recruit surveys will provide more information with which to assess the impact of environmental factors on recruitment strength, and will permit subsequent refinement of the pre-recruit abundance indices.

Sardine spawning seasonality has been investigated in the past and most researchers have described the spawning season as prolonged. A density-dependent study demonstrated spawning from August to March. This study was conducted under varying stock biomass levels, such as a pre-collapse period (1953–1964) and two post-collapse periods (1965–1975 and 1976–1987). As the sardine stock inhabits a highly variable environment and the biomass level has shifted in recent years, the spawning seasonality of sardine was re-examined. The relationships between gonad mass and fish length, the standardized gonad mass (*SGM*), a relationship between gonad mass and somatic mass, the gonadosomatic index (*GSI*), and the results of a 12 month histological study were used. Where *SGM* values exceeded 0.25, fish were considered mature.

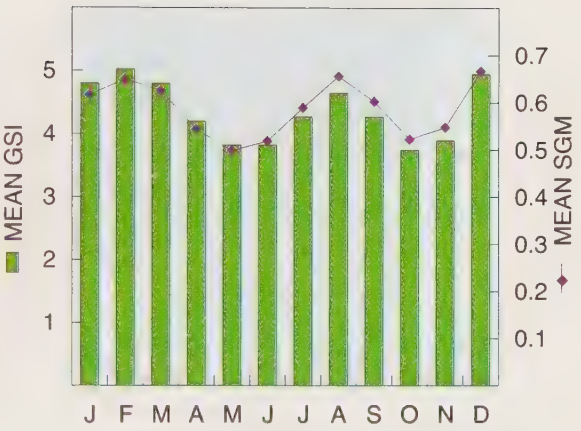

Fig. 8: Mean GSI *and* SGM *for female sardine from 1987 to 1997 commercial catches*

Researchers in Kwazulu-Natal argue that sardine spawn intensively during winter. Analysis of *SGM* and *GSI* from commercial landings for the period 1987–1997 revealed that sardine spawn for most of the year, but only to a limited extent during April, May, June and October (Fig. 8). Previous authors observed that, while the West Coast samples of sardine consisted either of recruits of the year or large, mature adults, the eastern Agulhas Bank (EAB) samples were dominated by one- or two-year-old sardine, with maturity commencing in the two-year-olds. Commercial catch distribution noticeably favours the West Coast (Fig. 9), while catches off the EAB are relatively less. Therefore, fish from the EAB could be under-represented in the samples obtained from the commercial catches and consequently the spawning seasonality pattern could be biased towards catches made on the West Coast.

In order to further investigate possible differences in spawning pattern between areas along the coast, a 12 month histological study that covered the West Coast, western Agulhas Bank (WAB) and EAB was undertaken. Ovaries were taken from fresh fish samples on board commercial purse-seiners, fixed in Bouin's solution and returned to the laboratory for histological processing. The study revealed that spawning indeed occurred during winter along the West

Fig. 9: Commercial catch distribution of sardine for the years 1987–1997

Coast and WAB (Fig. 10a) as well as along the EAB (Fig. 10b). Owing to insufficient samples being obtained, a rigorous comparison between the two areas along the coast was not feasible. Nonetheless, the higher incidence of mature fish in the samples taken during the months of June and July off the EAB could be an indication of a possible higher spawning rate there.

Fundamental to the management of any fishery is the direct sampling of the stock to obtain accurate measurements of the state of the population in terms of spawner biomass and information on the condition of individual spawners and recruits. In attempting to increase the efficiency with which pelagic shoals are sampled, a multisampling net attachment was tested on a recent research cruise. This device was cooperatively developed by SCANMAR and the Institute for Marine Research in Norway and tested, by in-house research staff, in order to make necessary modifications to allow its use in southern African conditions. The multisampler attachment is a mechanical device fixed to the cod-end of a trawl net; it is designed

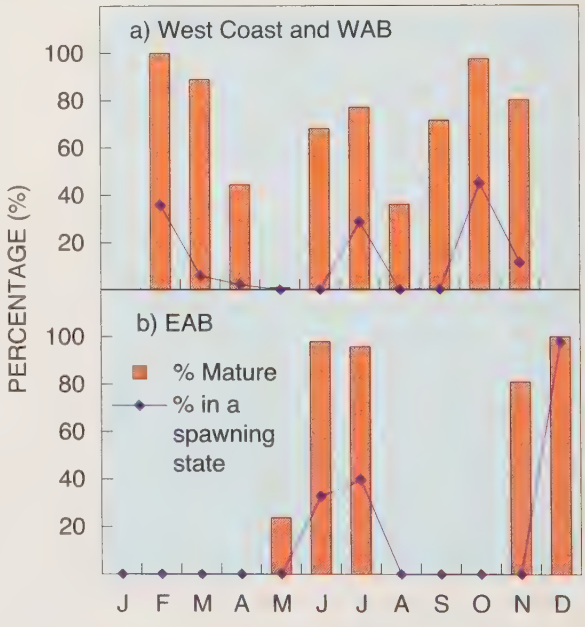

Fig. 10: (a) Mature sardine and sardine in a spawning state along the West Coast and WAB. (b) Mature sardine and sardine in a spawning state along the EAB, based on the 1997 histological study (n = 1197)

to allow three discrete, uncontaminated samples to be taken within a single trawl. The testing of the multisampler demonstrated that this is a useful device for sampling discrete layers of fish, and that it could be employed usefully for target identification during pelagic fish assessments cruises. Other uses of this device include investigating vertical migrations of demersal species (e.g. hake).

Demersal fish

The multispecies demersal trawl fishery, centred on the Cape hakes, *Merluccius paradoxus* and *M. capensis*, remains the most valuable sector of South Africa's fishing industry in terms of product value. The Total Allowable Catch (*TAC*) for hake remained at 151 000 tons for 1998, with the recommendation that it be caught on the West and South Coasts in the approximate ratio 2:1. For technical reasons, hake biomass surveys were not conducted during 1998, a concern because such biomass estimates are used to "tune" the surplus-production model and are therefore an essential component of the Operational Management Procedures (OMPs) in place for both West and South Coast hake stocks. The biomass surveys are regarded as vital for the continued sound management of South Africa's demersal resources. They provide a fishery-independent index of stock abundance, indices of recruitment, estimates of natural mortality and biological material such as the full size spectrum of hake otoliths necessary for updating the annual age-length key.

For West Coast hake stock assessment, a Fox surplus-production operating model has been adopted and a range of OMPs, based on age-aggregated data, have been evaluated. The essential trade-off between the options was one of larger *TACs* in the short-term v. greater resource recovery (and larger catch rate increases) in the medium-term. Fishing mortality options of $f_{0.05}$, $f_{0.1}$ and $f_{0.15}$ were selected for further comparisons and tests, and a large number of robustness tests, both deterministic and stochastic, carried out. An intermediate ($f_{0.075}$) option appeared to provide the best trade-off in terms of a high probability of recovery to the maximum sustainable yield (MSY) level within the next decade, a low probability of a decline in biomass over the same period, and a low chance of a decline in the total allowable catch (*TAC*) in the short term. This option also appeared adequately robust across the range of tests examined, provided particular care was taken to guard against failure to detect increases in fishing efficiency should research surveys to estimate hake abundance not continue. Management procedures based on age-structured production models (ASPM) were also examined and compared to that of the Fox-based candidates. Catch per unit effort (*cpue*) data, an integral input into the assessment, were standardized by means of General Linear Modelling (GLM), (see page 31).

Inconsistency and uncertainty in the age determination of the two Cape hake species is currently receiving attention. Previous studies on hake age determination used whole otoliths only. The identification of the first annulus using daily growth increments has been identified as a priority, and sectioning is therefore being undertaken. The aim of the project is to provide more accurate age parameters for use in the hake stock assessment procedure, which is moving towards age-disaggregated methods.

Histological sectioning techniques have revealed that both hake species spawn throughout the year, with minor peaks in autumn and spring. There is also evidence of a high degree of oocyte degeneration in most stages of ovarian maturity, and the quantitative effects of this phenomenon on spawning are still to be determined. To determine the spawning areas, the biological data from the hake biomass surveys of the South African West and South coasts in the period 1986–1997 are being analysed. Preliminary results show that hake spawn along the entire coast, *M. capensis* at depths between 50 and 340 m and *M. paradoxus* at depths between 160 and 500 m. The relationship between spawning, bottom oxygen concentration and water temperature is currently being investigated.

The experimental phase of the hake longline fishery ceased in 1998. The 1998 allocation for hake-directed longlining was as follows: 2000 tons of existing trawl quota was converted to longline and fished during the months July – December; 4 400 tons of the *TAC* was allocated specifically for hake longlining and that allocation was performed by the new statutory Fisheries Transformation Council. The permits for this last allocation were only released from 18 December 1998 onwards, and eventually the fishery was allowed to operate until 15 March 1999. This short catch period resulted in an oversupply of fresh hake on the overseas markets and a rapid decline in prices received.

Preliminary modelling was carried out during the initial pilot study on longlining to compare the effects of longlining and trawling using known selectivity parameters. The provisional results of these models were clear: for the same level of catch in a fishery (i.e. either trawling or longlining), longlining would result in a lesser reduction of the spawning stock than trawling. However, these assessments were made at the beginning of the pilot study when it was thought that the rate of natural mortality *M* of hake was fairly low. More recent analyses have indicated that *M* may be considerably higher than previously estimated and, under such circumstances, the effect of longlining is less optimistic relative to that of trawling. Additional modelling is required in this regard, while the impacts of discarding of small fish (trawling) and predation of hooked fish by seals (longlining) are yet to be incorporated in the models.

It has been recommended that hake longline allocations should be phased in gradually, but that they should not exceed 10% of the *TAC* until the impact of such catches on the resource, the selectivity of the catch method and the socio-economic effects of the fishery have been thoroughly investigated. A socio-economic investigation conducted during the hake longline experiment concluded that, although longlining was more labour-intensive than trawling, the latter industry utilized a vast labour force in land-based factories, where value-added fish processing occurred. The study concluded that a switch to longlining for hake would not result in a net increase in the number of jobs.

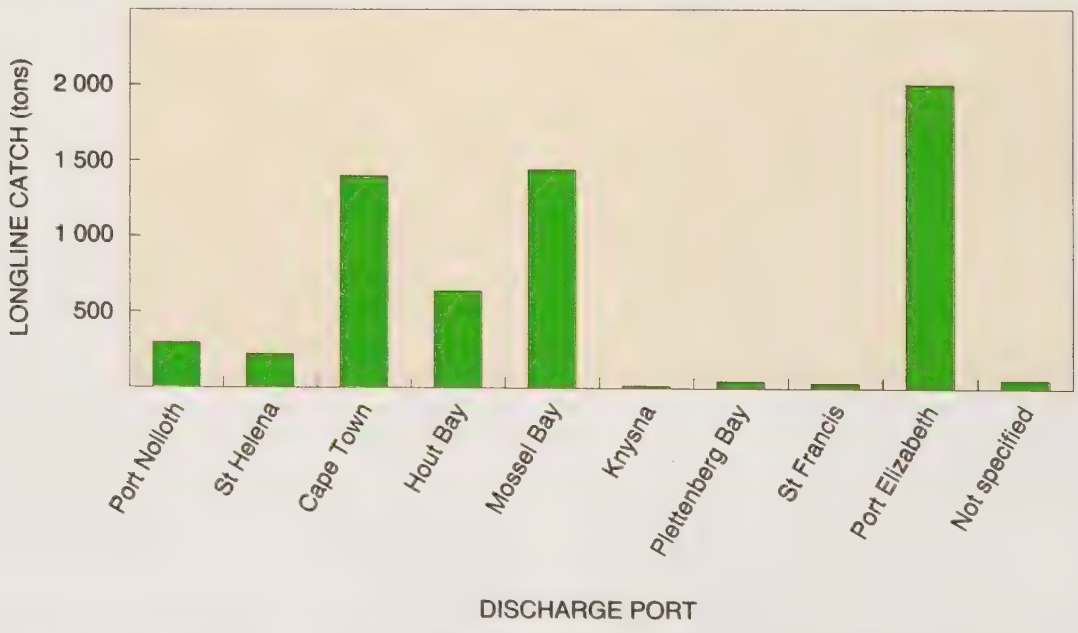

Fig. 11: Hake longline catches discharge from Port Nolloth (West Coast) to Port Elizabeth (East Coast)

The hake longline fishery is concentrated in two areas, one off the South-West Coast in the vicinity of Cape Point, where *M. paradoxus* is targeted, and the second off the South Coast between Cape St Francis and Mossel Bay, where *M. capensis* is targeted. In the latter region, this has resulted in a substantial increase in *M. capensis* catch, and any expansion of longlining there should be accompanied by separate assessments for the two hake species. Management of the longline fishery on a spatial basis may become essential because there is some concern that the longline fleet is increasingly shifting effort to the South Coast, causing increased pressure on the *M. capensis* stocks there. Landings of longlined hake for the period under review illustrate that Cape Town, Mossel Bay and Port Elizabeth are the most important discharge ports (Fig. 11), and illustrate the importance of the South Coast fishing grounds in the fishery. In general, it may well be that the hake resource can be harvested sustainably by a combined longline and trawl fishery, but effort levels in each and compliance with regard to permitted catches must be strictly controlled. Also, the impact of the combined fishing must be carefully assessed while relative catch tonnages must be carefully controlled.

Aspects of gear selectivity in handline, longline and trawl catches on the South Coast are being

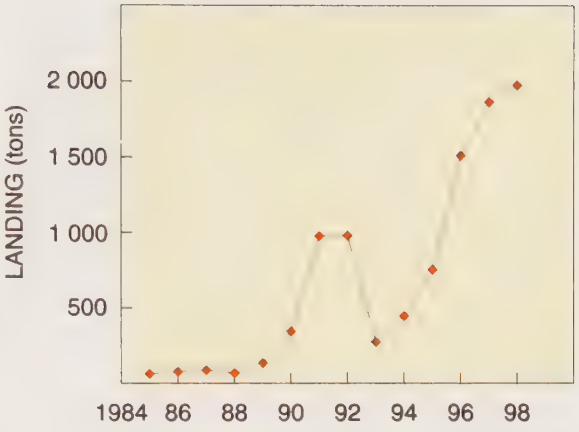

Fig. 12: Reported hake handline catches along the Cape South Coast

investigated. Each method is selective in the size and species of hake caught. Offshore trawlers catch both species of hake, whereas inshore trawlers, longline vessels and skiboats catch only *M. capensis*. The handline hake fishery has not been studied and its impact on the inshore hake resource is unknown. This sector is known to be growing rapidly (Fig. 12); handline catches are not monitored rigorously and the exact amount of hake being landed is unknown. Hake caught by handline are, on average, smaller than those caught by longline (Fig. 13). Estimation of the number of ski-boats active in this sector is

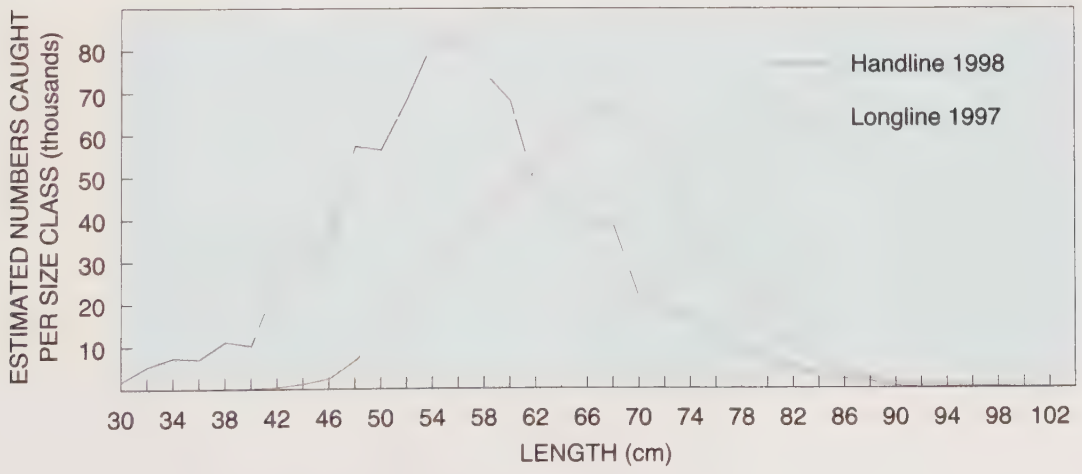

Fig. 13: Comparison between hake sizes caught by handline and longline

difficult as the vessels do not necessarily stay in one region. Some boats fish on hake for only a few months of the year and many of the vessels involved are not licensed.

Assessment of the Agulhas sole *Austroglossus pectoralis* stock using age-structured Virtual Population Analysis was hampered in 1998 because of the lack of a suitable index of abundance. Technical problems with the *F. R. S. Africana* meant that no survey biomass estimates were available, and GLM analyses have not yet been performed to increase the reliability of *cpue* as an index of abundance. In 1999, GLM analyses and improved assessment of the age structure of the stock are receiving attention. Validation of age using daily increments in otoliths to identify the first and second annulus is in progress. Length frequencies, derived from research survey data, are being assessed to follow the growth of strong and weak year-classes. Otoliths collected during the autumn research survey in 1997 were measured and analysed. Growth rates and otolith length/fish size relationships were similar for fish at depths 25–75 m and 75–100 m. In water deeper than 100 m, only females were collected. These fish were larger at age and the otoliths were smaller than fish of similar length in shallower water. These differences require further evaluation and have implications for age determination based on otoliths collected without reference to locality from commercial catches in 1998. There were differences in the size and age at maturity between females collected in water shallower and deeper than 75 m. Females matured younger and smaller in shallower water (Figs 14, 15). The appearance of juveniles in deeper water (>25 m) during peaks in winter winds are discussed later.

For horse mackerel *Trachurus trachurus capensis*, the lack of a reliable age-structured catch and

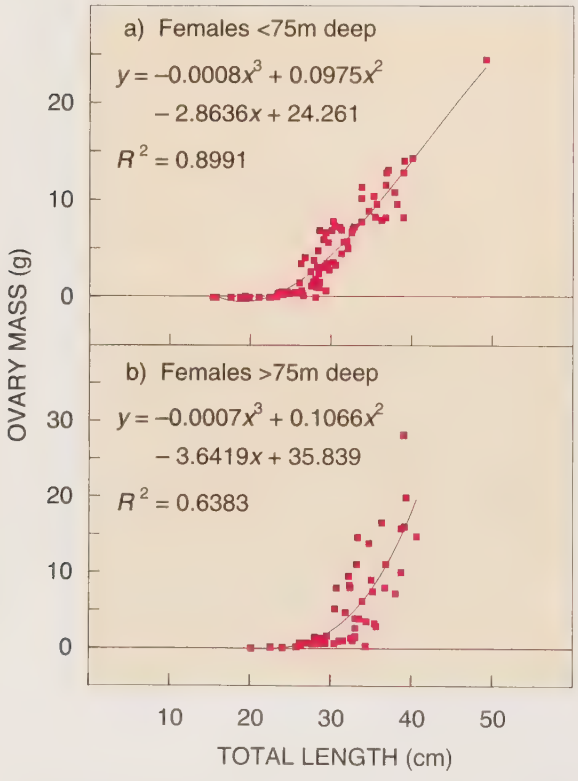

Fig. 14: Agulhas sole ovary weight at total length, at depths a) shallower than 75 m b) deeper than 75 m

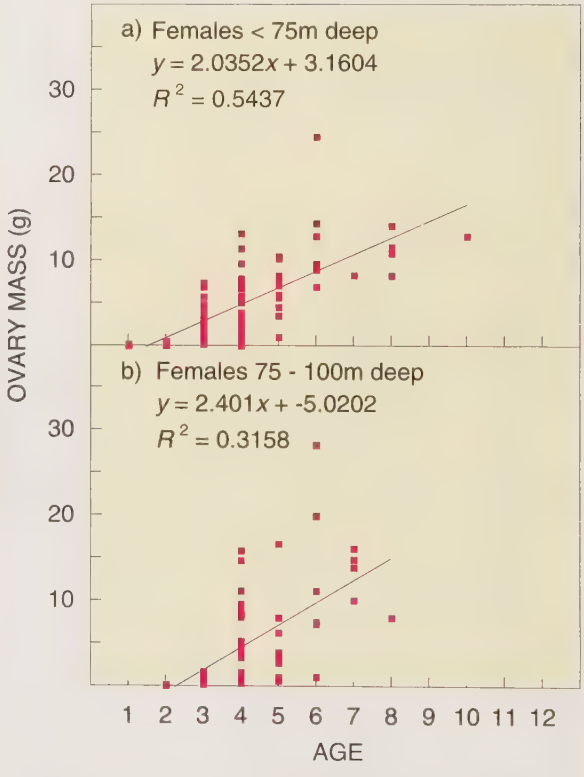

Fig. 15: Agulhas sole ovary weights at age, at depths a) shallower than 75 m and b) deeper than 75 m

cpue data series have hampered attempts at producing reliable stock assessments. A yield-per-recruit model, based on the Beddington-Cooke approach, has been used since 1993. In 1997, improved biological parameter estimates, as well as two additional parameters (variable recruitment and variability in the survey biomass estimate) were introduced into the model, yielding a much lower recommended catch. The precautionary maximum catch limit (PMCL) was reduced accordingly, from 58 000 tons to 34 000 tons in 1998. Relative biomass indices for the West and South Coast sectors of the horse mackerel stock are likely to be underestimates of the resource for several reasons. These include: the surveys are targeted at species other than horse mackerel; areas of high abundance on the upper continental slope are excluded; a large proportion of the stock is mesopelagic; and the surveys do not compensate for vertical migration. The vertical, nocturnal migration of horse mackerel is currently under investigation. That it occurs under isothermal conditions has encouraged the speculation that it is temperature-related, also some thermal influence was inferred from the observation that vertical migration occurs more extensively into midwater when strong thermoclines are present. Other possible determining factors are predator avoidance and feeding periodicity. A spring feeding study on horse mackerel on the Agulhas Bank revealed that they fed exclusively on the bottom and that stomach fullness peaked just prior to their evening ascent into midwater. There was no feeding at night while in the pelagic, even though there was plentiful food available in the form of zooplankton.

Little new information on the deep-water trawl fishery surfaced during 1998/99, largely because few dedicated fishing trips were undertaken. Estimated swept-area densities of oreo dories (0,8–8,6 tons.km^{-1}) were an order of magnitude higher than for orange roughy *Hoplostethus atlanticus* (0.0–0.8 tons.km^{-1}) off South Africa, but lower than the densities for orange roughy recorded outside aggregations off Namibia (0.6–39.0 tons.km^{-1}). The estimated density of oreo dories inside the 'Dory Patch' (8.6 tons.km^{-1}) is still one to two orders of magnitude lower than the densities of orange roughy inside aggregations off Namibia (89–641 tons.km^{-1}). This is an indication that the oreo dories do not form the dense localized aggregations characteristic of the orange roughy. All species of oreo dories have been lumped for this analysis, but it would be more appropriate to split assessments for the different species because they have different biological parameters. Separate catch limits for each species would decrease the risk of over- or underfishing a particular species.

Linefish

A new Management Protocol developed for the linefishery requires that future regulations for linefish be based on stock assessments and quantifiable reference points. However, it is also recognized that, owing to the large number of species involved/exploited, it will take several years for the status of all species to be assessed. As a result it has been necessary to prioritize species for research, and to develop a set of "stock status indicators" to guide the formulation of interim regulations. Although these "stock status indicators" include trends in catch composition, change in sex ratio (for those undergoing sex-change) and public concern, the most useful is historical change in *cpue*. According to the proposed Protocol, any stock which has demonstrated a reduction in *cpue* of more than 75% should be regarded as overexploited, promulgating suitable interim restrictions and initiating appropriate research as a priority.

Analysis of historical *cpue* for the commercial linefishery revealed that, in spite of massive technological advances, such as vessel motorization, nylon lines, echo-sounders, electronic navigational aids and on-board freezer facilities, the current catch rates of demersal linefish are dramatically lower than historical values, with most falling way below the 25% level (Table 1). Catch information from the trawl industry and recent stock assessments for silver kob *Argyrosomus*

Table 1: Mean catch per boat-year ± standard deviation for each of 11 important linefish species during the periods 1897–1906, 1927–1931 and 1986–1998. Data are provided only for regions falling within the main distributional range of each species. *% Current* is the current *cpue* value calculated as a percentage of the maximum historical value.

Species	Region	Catches per boat-year (kg)			% Current
		1897–1906	1927–1931	1986–1998	
Geelbek	SW Cape	9 784±4 079	812±481	243±59	2.49*
	S Cape	6 508±4 412	355±188	281±203	4.32*
	SE Cape	17 765±21 714	3 692±3368	258±97	1.46*
Silver kob	SW Cape	2 771±711	1 222±280	256±68	9.24*
	S Cape	3 551±976	9 739±1 739	763±174	7.83*
	SE Cape	14 857±9 448	13 516±5 244	578±130	3.89*
Seventy-four	SW Cape	40±27	28±31	0.04±0.06	0.09*
	S Cape	580±419	200±79	0.07±0.08	0.01*
	SE Cape	5 944±3 790	339±231	13±8	0.22*
Roman	SW Cape	425±225	560±248	71±13	12.65*
	S Cape	132±65	229±55	40±14	17.44*
	SE Cape	860±723	558±209	40±6	4.65*
Red stumpnose	SW Cape	196±91	187±19	8±1	3.90*
	S Cape	70±54	757±242	7±3	0.91*
	SE Cape	96±89	382±245	20±3	5.35*
Carpenter (inshore)	SW Cape	9 350±3 545	3 473±1 296	300±94	3.21*
	S Cape	1 468±766	3 481±1 056	166±56	4.77*
	SE Cape	3 574±2 797	3 107±1 872	925±291	25.88
Hottentot	W Cape	1 935±914	176±75	433±166	22.40*
	SW Cape	143±172	518±168	196±63	37.93
White stumpnose	W Cape	52±45	247±82	79±60	31.94
	SW Cape	173±179	260±149	126±53	48.27
	S Cape	344±159	416±90	0.8±0.8	0.20*
Yellowtail	W Cape – S Cape	483±526	146±51	289±63	59.83
Snoek	W Cape + SW Cape	4 669±3 131	5 999±2 694	3 454±1 360	57.58

* indicate those values falling below the critical 25% level.
(Refer to *Smith's Sea Fishes* for scientific names of species in tables 1–3.)

inodorus suggest that the trends in line catch rates indeed reflect trends in stock abundance (Fig. 16). In contrast to the demersal species, the catch rates of pelagic nomads such as yellowtail *Seriola lalandi* and snoek *Thyrsites atun* have not demonstrated the same dramatic declines. The key to the resilience of the latter is presumably their unpredictable movement patterns that effectively reduce fishing effort. It should be noted that baseline information before the onset of exploitation is not available, and rowboat catch rates for many species were in all probability highest in the mid 1800s. Moreover, although relevant catch data do not exist, the highest catch rates are expected to have occurred in conjunction with the technological explosion of the 1950s. As a result % current values calculated using 1850s or 1960s catch rates (as the denominator) are likely to have been even lower than those presented in Table I. Nevertheless, the recorded declines in *cpue* and those stock assessments which have been completed indicate that the majority of bottom-dwelling linefish have been heavily overexploited. Marine protected areas are widely accepted as one of the most effective management tools for the conser-

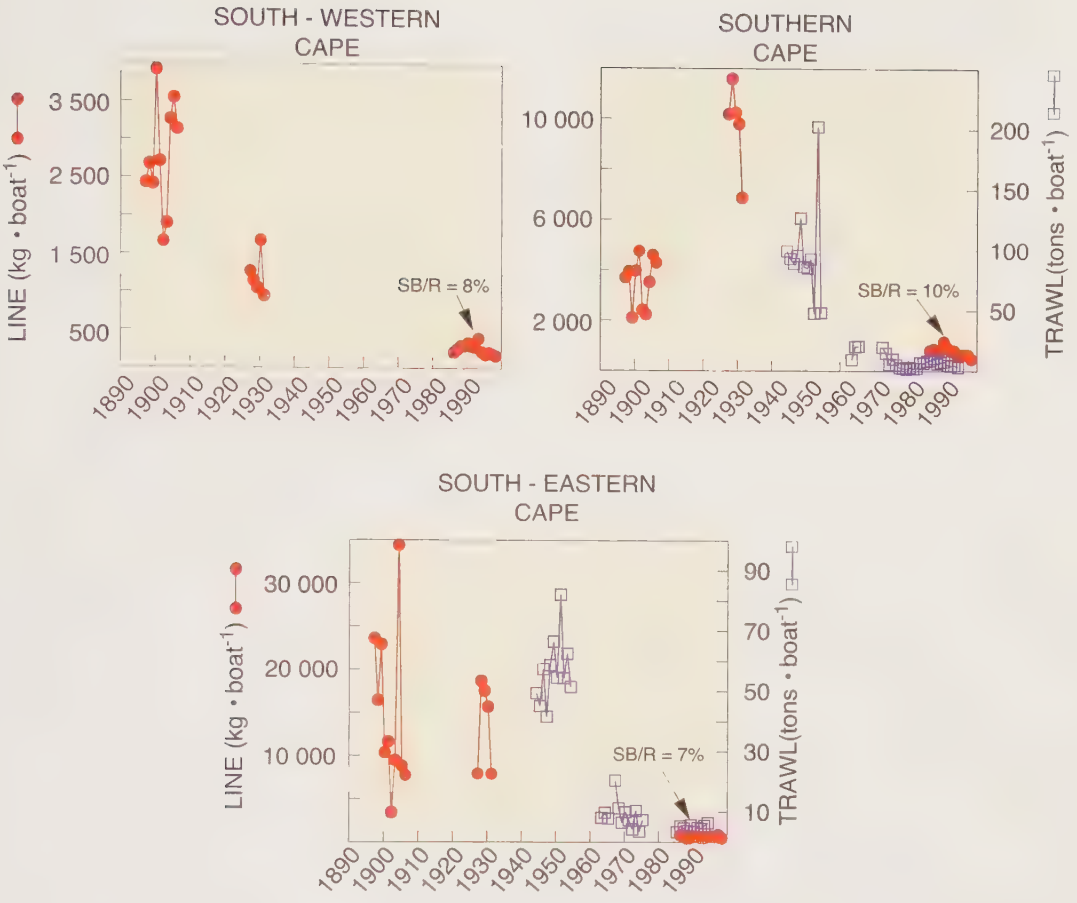

Fig. 16: Average annual catch per vessel for three stocks of silver kob caught by line boats (closed circles) and trawlers (open squares). SB/R values indicate current spawner biomass-per-recruit ratios calculated as a percentage of pristine. Values of <25% indicate stock collapse

vation of species with limited movement ranges. Completed mark-recapture studies suggest that many of the overexploited species have relatively small home ranges and that they would benefit substantially from appropriately placed reserves (Table 2, Fig. 17). Future research is planned to determine the optimal size of protected areas for each species.

In order to prioritize species for research and assessment, a procedure using Multiple Criteria Decision Analysis (MCDA) has been developed. The advantage of MCDA is that it provides a consistent and theoretically justifiable means of scoring alternatives (fish in this instance) on the basis of a number of criteria. The criteria can also be weighted in terms of importance and summed for each fish species, giving it an overall scoring or ranking. Five fishing sectors were identified as active in the fishery for linefish. These were recreational shore-angling, spearfishing, recreational boat, commercial boat and the beach-seine and gillnet fisheries. In all, 176 fish species have been recorded as having been caught by at least one of these linefish sectors over the past five years. Each species was scored according to its importance to each fishing sector, using criteria such as annual catch, the total number of people involved and conservation value, by incorporating trends in abundance,

Table 2: Classification of dispersal modes of various linefish species giving an indication of percentage returns and recaptures that had moved more than 10 km from site of release

SPECIES	Number of returns	Percentage returns	Average distance travelled (km)	Percentage moved > 10 km	Classification of dispersal modes
Hottentot	22	6.0	2.1	9.1	Resident/nomadic component
Blacktail	20	4.3	2.5	10.0	Resident/nomadic component
Dageraad	8	6.8	3.6	25.0	Resident/nomadic component
Red Stumpnose	70	9.6	0.7	4.3	Resident/nomadic component
Red Steenbras	109	21.0	56.6	20.2	Juvenile residency/adult migrant
Santer	237	13.1	5.2	22.8	Nomadic
Roman	238	5.9	2.2	10.5	Resident/territorial/nomadic component
Kob	317	10.0	31.3	47.0	Resident/nomadic component
Yellowtail	51	4.3	379.0	86.3	Highly nomadic

level of scientific knowledge and vulnerability of life history stages. This was done on both a regional (West, South, East and KwaZulu-Natal coasts) and a national basis.

Species rankings obtained from a preliminary analysis in which all criteria were given equal weights are shown in Table 3. Most of the important linefish species (in terms of total catch), appear within the top 20 when all sectors are combined or when the sectors and conservation criteria are grouped. Also, 13 of the 18 species

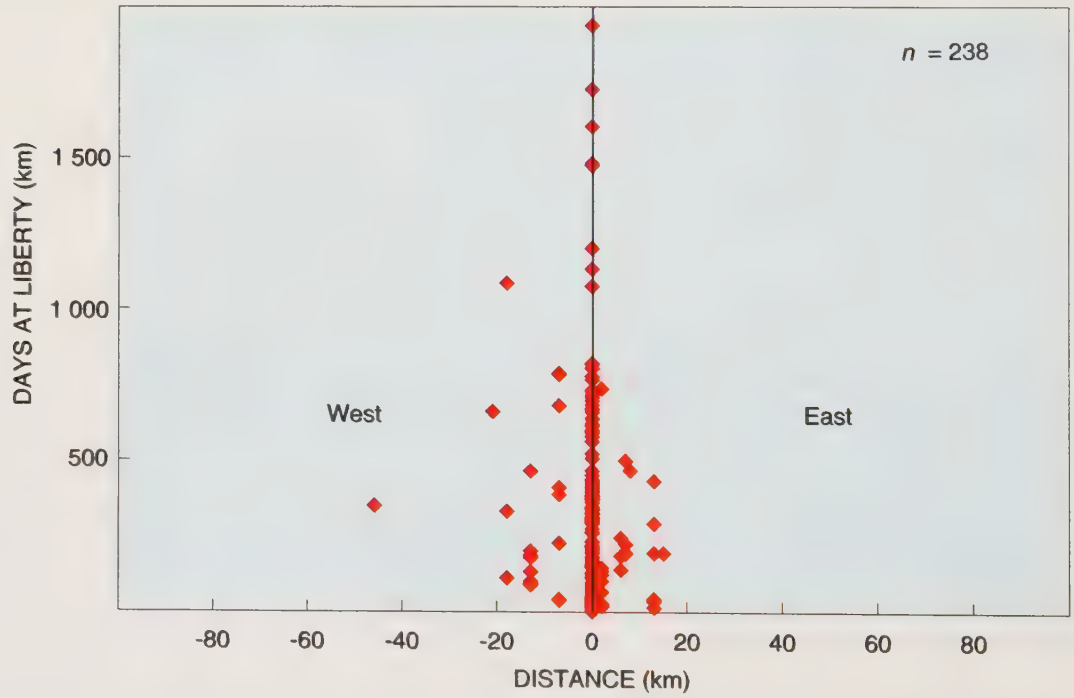

Fig. 17: Minimum distance traveled vs. days at liberty for Roman tagged in the S. Cape

Table 3: Preliminary priority species rankings by sector, for conservation and all sectors combined using MCDA.

Rank	Conservation	Shore-angling	Recreational boat	Spearfishing
1	White edged rockcod	Elf	Snoek	Hottentot
2	Slinger	Strepie	King mackerel	Roman
3	Scotsman	Dassie/blacktail	Roman	Bronze bream
4	False Englishman	Galjoen	Albacore	Cape knifejaw
5	Catface rockcod	Dusky kob	Geelbek	Queen mackerel
6	Kob spp.	Piggy	Yellowfin tuna	White musselcracker
7	Dageraad	Stonebream	Yellowtail	Leervis/garrick
8	Squaretail kob	Bronze bream	Hake	Belman/baardman spp.
9	Seventy-four	White steenbras	Silver kob	Slender baardman
10	Red stumpnose	Spotted grunter	Slinger	Galjoen
11	Englishman	Harder	Carpenter	King mackerel
12	White steenbras	Silver kob	Hottentot	John Brown
13	Zebra/wildeperd	Natal stumpnose	Kob spp.	Rockcod spp.
14	Red steenbras	White stumpnose	Soldier/santer	Yellowtail
15	Belman/baardman spp.	Cape stumpnose	Catface rockcod	Twotone fingerfin
16	Poenskop	Leervis/garrick	Queen mackerel	Zebra/wildeperd
17	Potato bass	White musselcracker	Panga	Bank steenbras
18	Silver kob	Striped mullet	Eastern little tuna	Poenskop
19	Yellowbelly rockcod	Hottentot	Red steenbras	Red stumpnose
20	Dusky kob	Lesser guitarfish	Tuna spp.	Dusky kob

Rank	Commercial boat	Beach-seine & gill-net	All sectors	All sectors & conservation
1	Snoek	Harder	Elf	Elf
2	Albacore	St Joseph shark	Strepie	Strepie
3	Kob spp.	Yellowtail	Snoek	Slinger
4	Yellowtail	Kob spp.	Dassie/blacktail	Snoek
5	Hake	Elf	Galjoen	White edged rockcod
6	Carpenter/silverfish	Yellowfin emperor	Dusky kob	Kob spp.
7	Geelbek	White steenbras	King mackerel	Dassie/blacktail
8	Tuna spp.	Galjoen	Roman	Scotsman
9	Hottentot	Silver kob	Albacore	Catface rockcod
10	Slinger	Dusky kob	Harder	Galjoen
11	Roman	Spotted grunter	Piggy	Dusky kob
12	Panga	White stumpnose	Silver kob	False Englishman
13	Soldier/santer	Smooth houndshark	Yellowtail	White steenbras
14	White stumpnose	Hake	Geelbek	Silver kob
15	Soupfin shark	Horse mackerel	Hottentot	Dageraad
16	Silver kob	Strepie	Bronze bream	Squaretail kob
17	Rockcod spp.	Dassie/blacktail	Stonebream	Red stumpnose
18	Red steenbras	Flathead/springer	Hake	Harder
19	Englishman	Striped mullet	Kob spp.	Seventy-four
20	Dusky kob	Belman/baardman spp.	White steenbras	Hottentot

chosen during an *ad hoc*, "gut-feel" prioritization exercise at a Tsitsikamma linefish workshop are also within the top 20. The remaining five, poenskop *Cymatoceps nasutus*, red steenbras *Petrus rupestris*, white stumpnose *Rhabdosargus globiceps*, leervis *Lichia amia* and musselcracker *Sparodon durbanensis*, appear on at least two of the sector or conservation lists. Surprisingly, small-sized

species namely strepie *Sarpa salpa*, piggy *Pomadasys olivaceum*, harders *Liza richardsonii* and stonebream *Neoscorpis lithophilus* feature strongly on the recreational and all-sector lists (Table 3). This is probably a result of all shore-based recreational fishers being lumped into one category, regardless of whether they were jetty-fishers with handlines or competition anglers fishing for sharks. The importance of the small-sized species is a reflection of the large number of people targeting them. It is also a reflection of the ever-increasing numbers of people turning to shore-angling as a means of subsistence.

The introduction of experimental longline permits for tuna in 1997 heralded a new development in the linefishery. Although local pole- and linefishers requested permission to longline tuna in the early 1990s, concerns associated with the allocation of fishing rights under the new Act, delayed allocation until 1997. In all, 20 experimental longline permits for tuna were then allocated to existing fishers and 10 to new entrants from previously disadvantaged communities. The aim of the experiment was to determine the viability of a pelagic longline fishery in South African waters, and to provide scientific information for the monitoring and management of such a fishery. Owing largely to the costs associated with obtaining equipment and suitable vessels, only 17 of these permits had been activated by 15 February 1999, which marked the end of the first phase of the experiment.

Although tuna were the intended target species, swordfish *Xiphias gladius* have constituted around 69% (467 809 kg) of the landed catch. This is believed to be the result of both an abundant resource and the fishing methods used, i.e. night time deployment of American style monofilament gear and light sticks. Swordfish fisheries around the world have characteristically demonstrated trends of boom and bust as a result of overcapitalization and excessive effort. To prevent this in the South African context, the number of participants involved in the fishery and a possible by-catch limit for swordfish, are currently under review. *Cpue* during the first phase of the experiment declined from an average of 3.4 kg per hook during the first three months, to 1.0 kg per hook during last three months. Genetic material is also currently collected and analysed in collaboration with the University of South Carolina to determine whether South African swordfish belong to Indian or Atlantic Ocean stocks. Other species landed include yellowfin tuna *Thunnus albacares* (12%), big-eye tuna *Thunnus obesus* (7%), Albacore *Thunnus alalunga* (2%) and sharks (7%). Catches are generally made at the shelf break along the West and South coasts. Fishing trips are typically some 10 days, with most of the fish kept on ice and destined for lucrative American and European fresh fish markets.

Cephalopods

Research on chokka squid *Loligo vulgaris reynaudii* continued in three basic directions: stock assessment and management research; basic biological research and environmental forecasting; and biological research in support of management.

An assessment of the squid stock was undertaken using fishery data and research estimates of biomass. The assessment estimated that the risk associated with the current level of effort deployed is high. In view of this, and the great sensitivity shown by the results to basic model assumptions, both maintenance of the closed season and a need to avoid increases above the current level of effort were recommended. As a precautionary measure, a recommended 10% reduction of the existing effort was implemented.

It is well known that chokka squid lay their eggs not only in the shallow inshore regions of the Southern and Eastern Cape but also in deeper midshelf waters. The shallow spawning grounds are subject to high environmental variability (12–18°C), whereas deeper water is relatively stable, although cold (9–12°C). It is unusual for

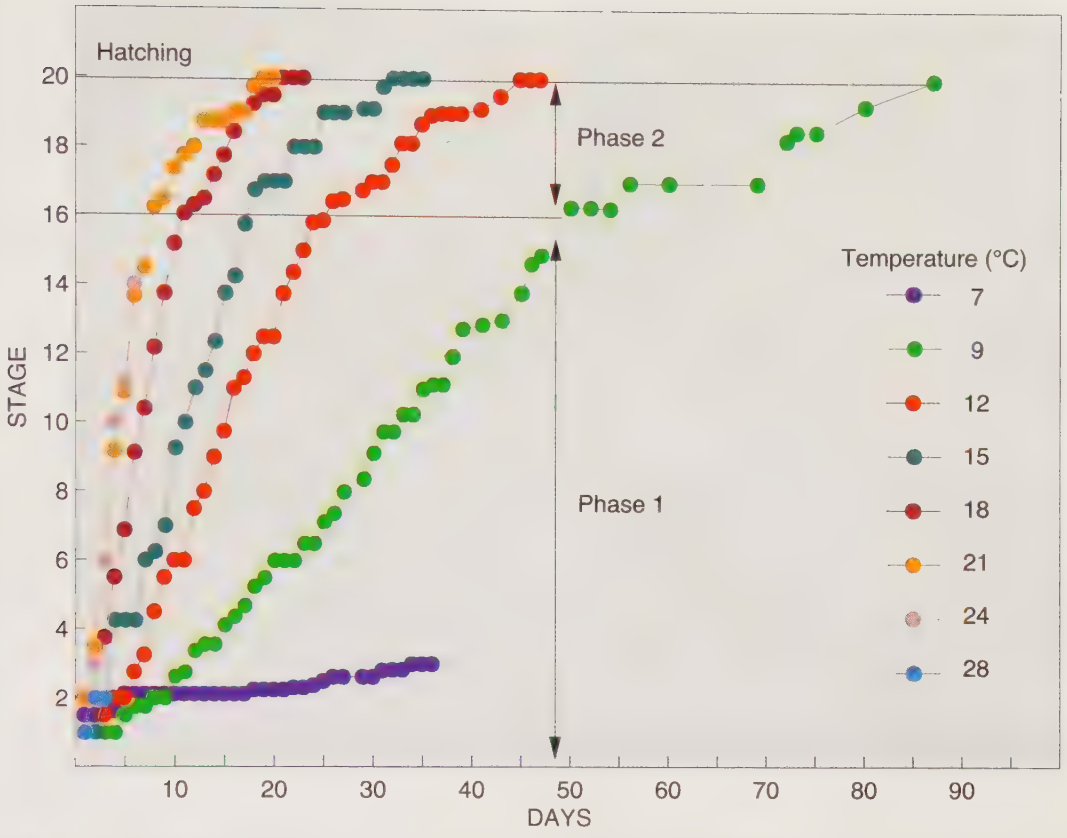

Fig. 18: Development curves for Loligo vulgaris reynaudii *eggs incubated at eight stable temperatures*

a species to spawn in two sharply contrasting environments, and earlier work had suggested that chokka eggs do not hatch when exposed to water temperatures of 10°C and below. Laboratory and *in situ* experiments were set up at the University of Port Elizabeth with the aim of resolving this apparent dichotomy. Temperatures were measured continuously on a known inshore spawning site and then analysed to determine the actual temperature range and frequency. Chokka eggs were collected by SCUBA divers and rapidly transported to aquaria inside environmentally controlled rooms. There, the egg pods were divided and subjected to eight different, stable temperatures ranging from 7 to 28°C. In total, 20 distinct embryonic developmental stages were identified and used as measures of growth. The results show that growth is a strong positive function of water temperature (Fig. 18). The optimal temperature range for development was between 12 and 18°C with hatching requiring between 47 and 23 days respectively. Outside this range, a high incidence of abnormal development occurred (Fig. 19). Eggs at 7°C turned opaque and did not develop, whereas at 24 and 28°C, development occurred in six and three days respectively, although gross abnormal growth of the mantle in these animals resulted in mortality. Hatching success at 9 and 21°C was 50%. A second series of experiments was undertaken to determine the effects of upwelling on egg development. In these, water temperature was varied under controlled conditions using a temperature gradient, duration of exposure at different temperatures and different egg stages as parameters. Finally, observations were made *in situ* on developing eggs exposed to natural variations in tempera-

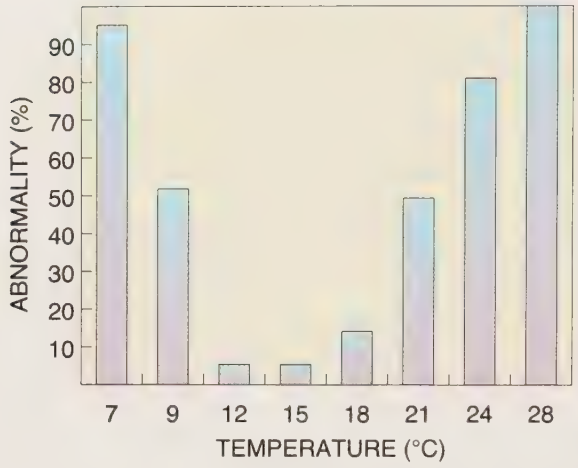

Fig. 19: The percentage of gross morphological abnormalities found at the different stable temperatures

ture. Results showed that, although changes in temperature either slowed or accelerated egg development, upwelling had little impact on hatching success.

The experiments indicate that the shallow inshore regions of this coast, despite the high environmental variablity, are very suitable for the development of chokka eggs. For 80% of the time, bottom water temperatures are in the optimal range for eggs, i.e. 12–18°C. The deeper, midshelf region is, however, far from ideal. The lower end of the naturally occurring temperature range is at the hatching success threshold. Not only do the eggs take as long as three months to hatch, but there is also a 50% abnormal development at 9°C, which results in mortality. At 10°C, this high abnormal development diminishes rapidly to 25%. Experiments are still in progress to determine the nature of the bottom temperature regime on the midshelf, as well as the scale of temperature fluctuations. However, it does seem that the preferred spawning grounds for chokka

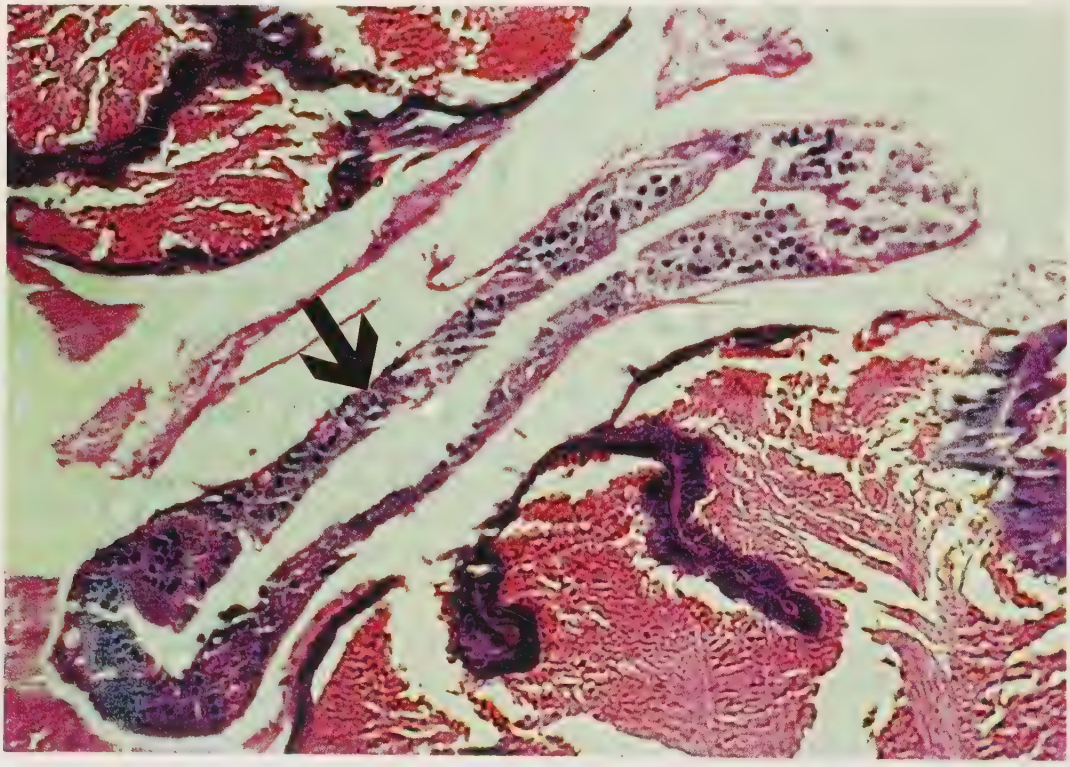

Fig. 20: A post-ovulatory follicle (POF) indicated by an arrow

squid are in the warmer, inshore areas. Currently, it is speculated that benthic turbidity events on the inshore regions of the coast periodically force spawners into the deeper, but clearer, midshelf waters.

Aspects of reproduction (maturation, spawning and spawning-related degeneration) and age determination (age determination techniques and age distribution in the metapopulation) are also being studied. Deep-water spawning concentrations of chokka squid were recorded and sampled for the first time. This may help to improve estimates of the relative importance of deep-water spawning, currently estimated to contribute about 20% of the total spawning effort. These estimates may be used for predicting squid abundance one year ahead, as well as for determining various biological parameters (e.g. natural mortality) used in stock assessment.

Research on squid reproduction in 1998 focused on post-ovulatory follicles (POFs). The follicles are layers of ovarian cells surrounding developing oocyes. After ovulation, the follicles begin to deteriorate and are then classified as post-ovulatory follicles (Fig. 20). Their state of degeneration assists in gauging the time elapsed between the various spawning episodes and the time of capture, which in turn is used to calculate the fraction of females spawning per day. Histological examination of ovaries, obtained at regular intervals over 24 h, allows classification of POFs into five stages. The frequency of occurrence of POFs in the ovaries confirmed serial spawning in this species. An important implication of this study is that the rate of resorption of POFs helps to determine the number of eggs spawned per batch and the time required for subsequent spawning.

Age determination techniques for chokka are now sufficiently developed to address the hypothesis formulated in 1998 that, by avoiding disruption of spawning behaviour, spawning success improves and the chokka fishery benefits from a closed season during spawning.

Abalone

Nearly all field time and resources of the abalone *Haliotis midae* research team are directed into the fishery-independent diving surveys, which can only be carried out in calm sea conditions. These diving surveys are an essential resource monitoring tool, because the interpretation of fishery data such as catch per diver hour has become increasingly complex with the continued inclusion of new participants in the fishery, as well as changing marketing practices. Data from the dive surveys are to be incorporated into resource assessment models.

Monitoring of the effects of the movement of rock lobster *Jasus lalandii* into two of the four main fishery zones (C and D) continues. Predation by lobster on sea urchins, which serve the function of providing shelter for juvenile abalone, continues. As a result of the absence of sea urchins, recruitment of juvenile abalone into the fishery has been severely reduced. This will result in declining yields in the future in these two zones which have traditionally supported around 40% of the annual TAC. Lobsters have also been observed attempting to feed on the epipodial fringe of large adult abalone.

Recreational fishers remain a major component of the fishery, and telephonic surveys of the participants continue to be a vital source of data on this sector. The temporary limiting of abalone collecting to weekends only in 1998, as well as limiting the numbers of permits sold, had the effect of reducing landings to 220 tons for the 1997/98 season. Previously landings had fluctuated at around 480t (Fig. 21). A new development in management of the recreational fishery has been the incorporation of a specified recreational TAC as part of the global annual abalone TAC. The recreational TAC was set at 158.5 tons for 1998/99, and in order to limit landings to this amount, collection was limited to weekends and public holidays only, for a four-month period. Continued close monitoring of this sector will be necessary to determine the effectiveness of these management changes.

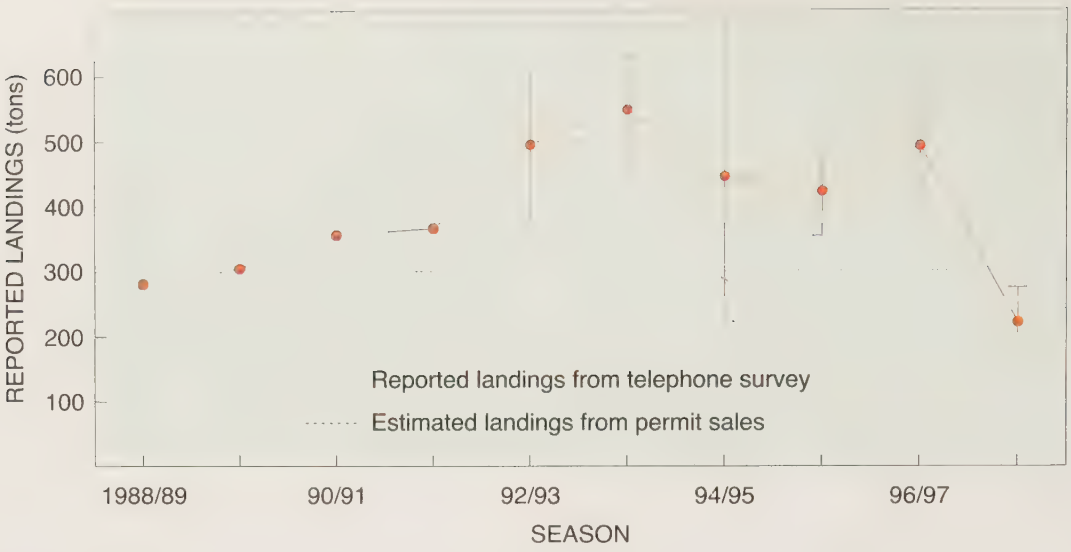

Fig. 21: Recreational abalone landings for the seasons 1988/89–1996/97

Pilot caging studies have been carried out to determine experimentally the effect of rock lobsters in the fishing zones east of Cape Hangklip. Results indicate that present cage designs are robust enough to withstand winter sea conditions, but that larger enclosures should be investigated.

Fig. 22: Loading poached and discarded shells from the Buffeljags area onto a truck

Poaching remains a major threat to the continued viability of the abalone resource. The almost complete denudation of the Mudge Point/ Hawston area of Zone C has resulted in the reduction of the TAC for that zone to 15 tons, from a high of 170 tons in 1990/91. Despite recent efforts to intensify control measures, including greater involvement of the police, poaching continues, and sublegal abalone continue to form a major proportion of the illegal take. Additionally, poaching has expanded to Zone A, in particular the Buffeljags – Quoin Point area, a zone currently supporting a TAC of 185 tons. Future TAC cuts are likely unless this (Fig. 22) is halted.

Abalone ranching (the release of artificially reared juvenile abalone into the sea for later harvest) has been proposed as a partial solution to the denudation of wild stocks by poaching. Research projects aimed at investigating this possibility on the West Coast and in the Eastern Cape have been initiated. These are being undertaken by a number of research institutions, with in-house cooperation.

Seaweed

There has been increasing interest in cultivating the agar-producing seaweed *Gracilaria* at Saldanha Bay and St Helena Bay, both as a source of agar, and as feed for farmed abalone. Until 1997, research illustrated the potential and some of the problems in Saldanha Bay, and in November 1998 an entrepreneur began commercial cultivation of the species (Fig. 23). Current efforts are aimed at advice and providing some research back-up.

Meanwhile, cultivation experiments in Vioolbaai, St Helena Bay, which started in 1997, have shown that, in summer, *Gracilaria* grows slightly faster there than in Saldanha, where surface nutrients become very low. Water temperatures in Vioolbaai seldom rise above 17°C, and nutrient levels are generally high enough to maintain growth at between 3 and 5%·d^{-1}. However, a

Fig. 23: Workers threading Gracilaria *onto netting lines prior to planting in the sea at Saldanha Bay, where cultivation of this red seaweed is being tried in the mariculture lease area*

major problem with St Helena Bay is the occasional occurrence of hydrogen sulphide eruptions ("black tides"). In May 1998, one such event killed all the *Gracilaria* and all fouling organisms on the test system, the kelp and mussels on adjacent reefs and jetties, and most of the other seaweeds and sessile animals (except anemones) in the area. Clearly, any mariculture in St Helena Bay will be vulnerable to these events, which as far as possible will have to be planned for.

One of the major problems in the cultivation of *Gracilaria* worldwide is epiphytic algae (Fig. 24). These are "pest" seaweeds that grow on the *Gracilaria* and reduce yields by competing for

Fig. 24: The green mutant strain of Gracilaria gracilis, *heavily infested with epiphytic* Ceramium *(visible as furry, red plants). The green mutant is particularly useful in studies on red epiphytes, because otherwise the colour of normal red* Gracilaria *is so similar to that of the epiphytes that they are difficult to separate and quantify*

light and nutrients and increasing mechanical drag. Overseas, attempts to combat epiphytes have involved treatments with bleach or solutions of other chemicals. The main problem epiphyte here (and an important one in some other countries, e.g. Chile) is *Ceramium*, a fine, filamentous red alga that can make up a significant proportion of the harvested crop. In recent experiments in St Helena Bay, *Ceramium* infestations have been significantly reduced, and *Gracilaria* yields improved, by immersing the seaweeds in freshwater for 5–10 minutes (Fig. 25) before planting them out in the sea. The *Gracilaria* is completely unaffected by the osmotic stress of a brief freshwater treatment because the tissue is many cells thick, dense, with a compact cortex (outer cell layer) and thick cuticle. The *Ceramium* is delicate, with branch tips of single-celled filaments, into which freshwater moves rapidly, causing discolouration and even lysis of the cells within minutes (Fig. 26). Although the corticated, basal parts of the *Ceramium* survive and produce new branches, this treatment slows their growth significantly, and should be useful in future farming of *Gracilaria* in South Africa and other countries.

A project to map the extent and biomass of kelp beds along the West Coast was started some years ago. Infra-red aerial photographs showing the surface kelp canopy at low spring tide are now being digitized under contract using a GIS programme. The beds have also been mapped manually from projections of individual slides through an enlarger. The methods will be compared and calibrated by further ground-truthing. The final aim is to produce a GIS database that can be modified if kelp beds change,

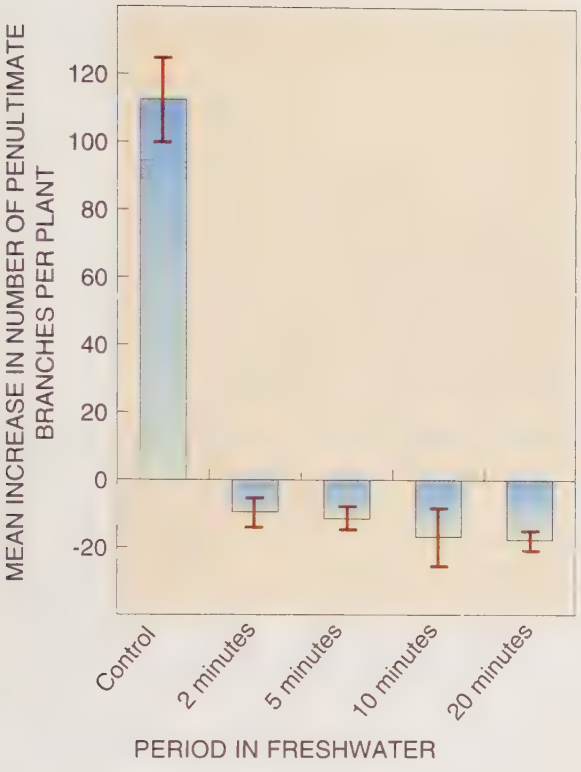

Fig. 25: Results of an experiment to reduce the amount of the epiphyte Ceramium *on cultivated* Gracilaria *by immersing the plants in fresh water prior to cultivation. The ratio of* Ceramium/Gracilaria *is significantly reduced by 5 or 10 minute pre-treatments. The plants were grown in suspended cultivation in St Helena Bay, and all were heavily infested with epiphytes before treatment. (n = 10, and 95% confidence limits of mean shown)*

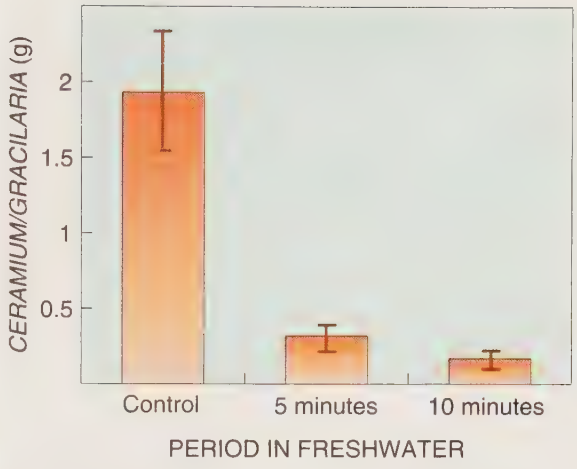

Fig. 26: The effect of freshwater treatment on the number of penultimate branches in the pest epiphyte Ceramium. *The plants were immersed in freshwater for periods of 2, 5, 10 or 20 minutes, or not at all (Control). After two weeks in laboratory culture, all treated plants had fewer branches, while untreated plants had produced more than 100 new branches each (95% confidence limits of means shown)*

used in allocating kelp concessions and (at an appropriate scale) to monitor the effects of harvesting.

The increase in the number and size of abalone farms on the coast of the Western Cape has intensified pressures to harvest a constant supply of fresh kelp as abalone feed. Research has shown that the effects of harvesting vary at different parts of the coast, and that kelp beds recover most rapidly where there are few benthic grazers, such as urchins, turbinid snails, limpets and abalone. A harvesting experiment was set up in such an area, near Jacobsbaai, north of Saldanha, about four years ago. In a 400m^2 area, all kelps with stipes longer that 50 cm were cut just above the holdfast. The total kelp biomass returned to control (unharvested) levels within 2.5 years, as did the mean density (number of kelps·m^{-2}), mean stipe length, fertility (as number of fertile fronds·m^{-2}) and various other indices of kelp demography. However, kelps in the harvested area had a slightly lower mean frond mass than in adjacent controls, and regrowth was measured again a year later. Results indicate that all kelp size and biomass indices had returned to control levels within 2.5–3.5 years. Harvesting the kelps did not cause a detectable change in the composition of understorey communities, as determined by a range of diversity and biomass indices. Current experiments are looking at the possible effects of harvesting on the biomass and diversity of the algal epiphytes that grow on the kelps. These seaweeds can attain a high biomass and are an important source of food and shelter for a range of animals, from crustaceans to fish.

Inshore between Cape Hangklip and Hermanus, numbers of rock lobsters have increased dramatically in recent years. Increased predation by the lobsters has severely reduced the numbers of benthic grazers such as turbinid snails, sea urchins and small abalone. As part of a study of these ecosystem effects, monitoring of benthic communities, particularly seaweeds, has been carried out for the past two years, at two sites in the affected area (Hawston and Betty's Bay) and one east of it (Romans Bay, near Gansbaai). Results from these surveys show negative correlations between the numbers of rock lobsters and benthic grazers, and between benthic grazers and recruitment of kelp juveniles. This supports the idea of a "domino effect": lobsters are reducing the numbers of grazers, and more kelp juveniles are surviving. Mature kelps are not susceptible to benthic grazers, and are as yet unaffected. Fluctuations in the cover of other seaweeds cannot at this stage be related to changes in benthic grazers, and may be a result of other environmental variables. This study is continuing.

Rock Lobster

During 1997, an Operational Management Procedure (OMP) was introduced for the West Coast rock lobster fishery. Among the principle aims of this strategy was the attainment of a 20% increase in harvestable biomass over a 10-year period, relative to that estimated to be present at the beginning of the development phase of the OMP. Another objective of the OMP was to provide an impartial, transparent, standardized method of determining *TAC* recommendations from year to year. Despite some setbacks, such as the large strandings of lobster on the West Coast during 1997, 1998 and 1999, and slower somatic growth rates than were predicted, it is believed that the OMP has so far been effective in achieving these goals. Because the OMP was instituted for an initial period of three years, the 1999/2000 *TAC* recommendation will be the last under this management regime. Revisions of the OMP are currently underway, and a new OMP should be in place by the end of 1999 and implemented during the 2000/2001 *TAC* deliberations.

The most severe complications experienced in recent seasons have involved a series of severe lobster strandings. Since the major event at Elands Bay during April and May 1997, when in excess of 1 500 tons were stranded, there have been further strandings at Dwarskersbos (about 50 km south of Elands Bay) during May of both 1997 and 1998, and at Elands Bay again in April 1999. All of these stranding events have been associated with extremely low concentrations of oxygen nearshore, which have been caused by decomposition of large phytoplankton blooms. Combined efforts of the West Coast rock lobster fishing industry, the South African Police and Defence Force and in-house personnel have resulted in about 20% of the stranded lobster being returned to the sea, in areas beyond the limits of the plankton blooms. Nevertheless, the recent increased frequency of occurrence of these devastating events is a matter of concern and their consequences will have to monitored carefully.

In contrast to the depletion of lobster populations in the north, those inhabiting the southern grounds at Dassen Island and the Cape Peninsula seem to be thriving. Furthermore, it has been estimated from recent surveys that about 10% of the entire West Coast rock lobster population is currently resident east of Cape Hangklip, an area closed to commercial fishing. Naturally, patterns of exploitation have mirrored this distribution, and lobster populations are thought to be fully exploited throughout their range, excluding lobster sanctuaries.

Assessment of the lobster populations inhabiting lobster sanctuaries is long overdue. Many of these conservation areas have been in place for some time, but little or nothing is known regarding their efficacy in terms of conserving examples of pristine size structure, contributing meaningfully to post-larval recruitment or enhancing catch rates in surrounding fishing grounds. Surveys during 1998 indicated that lobster sanctuaries are particularly ineffective, probably because of a

lack of suitable habitat within their boundaries. If surveys during 1999 confirm this observation, some consideration will have to be given to the value of maintaining the conservation status of such closed areas.

In support of existing fishery independent monitoring surveys (FIMS), which operate from commercial vessels in waters deeper than 15 m, a new survey was initiated to investigate the distribution of lobster in waters between 15 m depth and the shoreline. An initial survey of this nature was conducted during February 1999, using an inflatable vessel to set hoopnet transects along a randomized grid of sample positions between the Olifants River and Danger Point. The results of this survey will elucidate some areas of concern in the existing FIMS technique.

To further investigate trends in resource strength, a preliminary research programme has been established to monitor the settlement rate of early post-larval lobster pueruli at three sites along the coast. Although this approach has been successfully employed in Australia and New Zealand, the exposed nature of the South African west coast has made the collection of a regular series of samples problematic. Nevertheless, the prognosis for this project is favourable, and positive results are expected in the near future.

Biomass estimates of the South Coast rock lobster *Palinurus gilchristi*, based on *cpue* trends, have indicated a continuous decline since the 1988/89 season. To alleviate the fishing pressure on the resource, a phased reduction of the *TAC*, from 477 to 402 tons over four years, was indicated in 1994. This process came to an end last year, with a 402 tons *TAC* implemented for the 1997/1998 season. However, the *TAC* reductions hardly seem to have impacted on the decline in biomass, which now appears to be some 50% of that estimated for 1988/89.

It is possible, however, that this decline is (at least in part) a reflection of trap-saturation arising from the surfeit of traps now used in the fishery (Fig. 27). In the late 1980s the restriction on the number of traps per vessel was removed. This, coupled with the purchase of larger vessels by some companies in the early 1990s, allowed skippers to try to increase their catches by simply increasing the number of traps deployed and the trap soaking time. This may have caused a

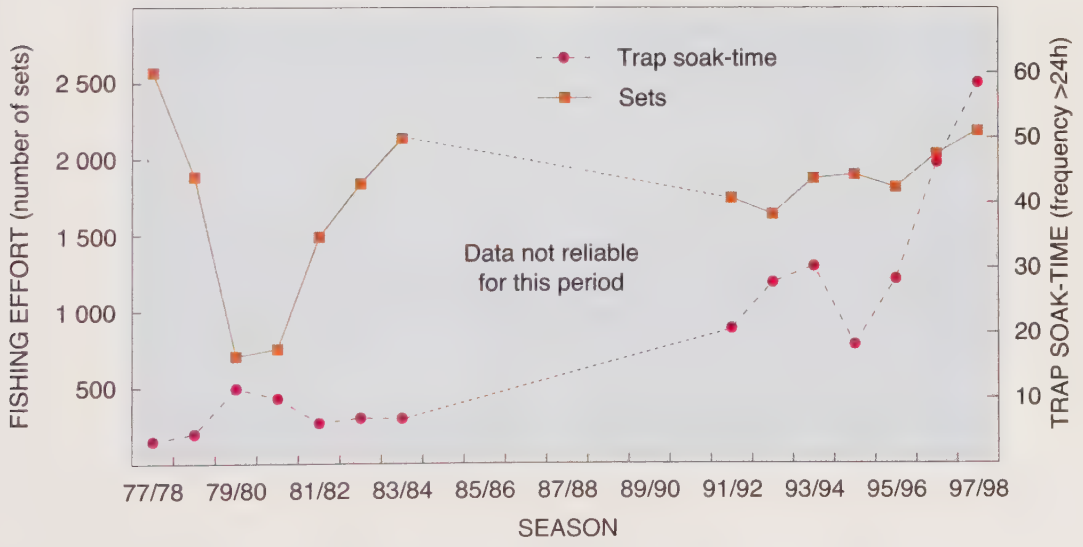

Fig. 27: Trends in fishing effort (measured as numbers of sets and trap soak times) in the South Coast rock lobster fishery

reduction in trap efficiency and an apparent decline in *cpue*. An effort reduction experiment to quantify the effect of trap saturation on *cpue* is described elsewhere in this issue.

Pending the results of the effort reduction experiment, the *TAC* for this fishery was set at 402 tons for 1998/99. A lack of scientific evidence to support the trap-saturation hypothesis, and a continued downward trend in *cpue* in the 1998/99 season, may necessitate a marked *TAC* reduction in the 1999/2000 season.

Several permits for the 1998/99 season were granted to new applicants. To accommodate these new quota-holders, quota allocations to existing quota-holders were reduced. New quota-holders all undertook to develop their own processing facilities and purchase their own fishing vessels within two years. To date, however, vessels, crews and processing facilities of established companies are hired.

A four-year experiment to determine the commercial potential of a trap-fishery for Natal deep-water rock lobster *Palinurus delagoae* was conducted between 1994 and 1997. The observer-based experiment was undertaken jointly with two commercial fishing companies. The experimental design was structured into an experimental (fixed fishing positions) and a commercial phase (no restriction on fishing location) during each year. Over the four years of the experiment, catches of *P. delagoae* declined from 89.5 to 7.4 tons, and the by-catch of slipper lobster *Scyllarides elisabethae* declined from 30 to 2.0 tons. Standardized *cpue* decreased from 0.61 to 0.16 $kg \cdot trap^{-1}$, and the average size of lobsters caught declined annually. It is estimated that trapping has reduced the spawning biomass to 30% of its 1994 level.

The rate at which the trap-catches declined, even with a cautious approach to the experiment, suggests that the four years of trapping constituted a mining-out phase, with the large catches in the first two years comprising biomass accumulated over a long period. Recovery of the portion of the stock targeted by trap-fishers (i.e. adults in depths <350 m) to a level where it will again be economically viable to fish, is expected to be slow. This recovery is hindered by slow somatic growth to adulthood (est. 0 – 6 mm carapace length per year) and by the impact of the traditional East Coast multispecies crustacean trawl fishery, which accounts for 10 – 30 tons of immature and small lobsters per year. The trawl fishery limits the numbers of survivors to adulthood, which is the preferred catch of trapfishers. A multi species crustacean trawl fishery (including *P. delagoae*) therefore remains the method of choice in Kwazulu-Natal.

HIGHLIGHTS OF SUPPORTING RESEARCH

Re-standardization of the hake cpue data

Central to biomass assessment of the Cape hakes is catch per unit effort data *cpue*, because it is assumed that *cpue* is proportional to abundance. To understand the importance of an accurate cpue estimate, one must first take a look at what *cpue* data are, and how they are used in assessments. Many stock assessment models require as input an index of abundance. This is simply a data series that is linked in some way to the abundance (biomass) of the resource, so that year-to-year changes in the index mimic those in the resource. A commonly used index is the catch rate or *cpue*. *Cpue* is the amount caught (mass or numbers) divided by the amount of fishing effort. Effort can be measured in various ways, e.g. the time (hours or days) spent fishing or the number of hooks, traps or nets deployed.

The use of *cpue* stems from the reasoning that it should be easier to catch fish if there are more fish, i.e. as the biomass increases so will the *cpue*. Unfortunately, there are many factors other than fish abundance that can also influence *cpue* and it is essential to account for these factors in order to preserve proportional relationships between *cpue* and abundance. Factors other than abundance that influence *cpue* fall into two categories, those that affect catchability of fish (changes in fishing strategy) and those that affect fish availability (environmental conditions).

One major influence on catchability is vessel efficiency. A larger, more powerful trawler can tow a larger net and should therefore be able to catch more fish per unit of time than a smaller, less powerful vessel. Fitting a Global Positioning System (GPS) or an improved fish-finder may enable a fisher to locate favourite fishing sites or find fish shoals more quickly, so improving efficiency. Many other factors, such as fishing area, season, bycatch and changes in fishing strategy, to name but a few, also influence the catch rate. Gradual improvement in the efficiency of the fishing fleet could result in a gradual increase in the *cpue* that is unrelated to an increase in biomass. If this happens, then estimates based on the biased *cpue* trend will be overoptimistic and could lead to overexploitation. Conversely, changes in fishing strategy could result in a *cpue* trend that increases at a slower rate than biomass.

The advent of powerful computers and programs has made application of generalized linear modelling (GLM) techniques possible. This has given researchers a powerful new tool to standardize catch rate data and accounts for the large amount of effort that has gone into this important line of research over the past few years.

The hake *cpue* series used in past assessments was standardized by applying power factors that were crudely estimated; no adjustments were made for technological improvements and shifts in fishing patterns. Restandardization of the *cpue* data by means of a GLM was recently made possible by the conversion of these data into a format suitable for analysis. Attention was focused mainly on restandardizing the West Coast hake *cpue* data, for which a number of factors led to the development of the final model adopted.

A bycatch *cpue* factor is included in the model to account for fishing effort exerted on other species (given that only the total effort exerted is known). One would expect that, as bycatch *cpue* increases so hake *cpue* would decrease, but both positive and negative correlations were found between hake and bycatch *cpue* (Fig. 28). The

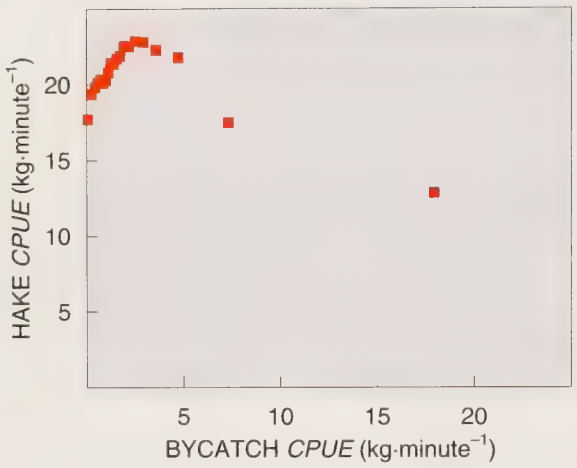

Fig. 28: Average West Coast hake cpue *and bycatch* cpue *in 5%ile intervals*

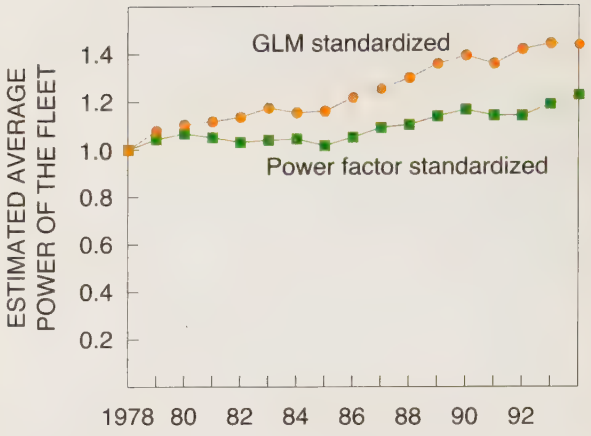

Fig. 29: Effective average power of the West Coast fleet

positive correlation is most likely a result of environmental factors that affect both hake and bycatch *cpue* in the same direction. As the bycatch *cpue* factor in the model accounts for effort directed away from hake (the negative correlation portion), it was necessary to remove the positive correlation effect by adopting an iterative procedure to adjust the bycatch *cpue.*

Extensive use of codend liners during the early years covered by this study would have impacted the *cpue* of small hake because smaller hake would have escaped in the absence of liners. It was therefore argued that the *cpue* of large hake would be more reflective of resource abundance. Consequently, separate GLMs were performed for "small" and "medium+large" hake respectively. The results indicated that the *cpue* of small hake declined substantially (by 3.6% per year) whereas that of medium and large hake increased (by 4% per year) over the period 1978 – 1994. While these observations appear to be contradictory, the discontinued use of codend liners may explain the decreased catches of small hake. There are, however, reservations that the separation of catches into size-classes reflects rough estimates by the skippers, and hence the comparability of size categories over time and between companies is questionable.

Although the nominal *cpue* (hake catch divided by actual time trawled) for the West Coast stock has increased steadily over the period 1978 – 1994, at a rate of 3.8% per year, the result from the model that adjusts for bycatch indicates only a 0.6% increase in hake abundance per year. This is inconsistent with industry's perception that there has been a substantial improvement in the resource between 1978 and 1994. Three factors appear to have contributed to the difference between the GLM results and the Industry's perception:

(i) there has been an increase in the effective fishing power of vessels in the fleet (Fig. 29);
(ii) vessels have moved to fishing in areas (e.g. deeper waters) where catch rates tend to be higher;
(iii) although there has been an increase in fish density in deeper water over time, this is more than offset by a simultaneous decrease in fish density in shallower water (Fig. 30).

The standardized *cpue* results also appeared to be inconsistent with research survey results. This discrepancy may be explained by the fact that fewer younger fish are currently being caught than in the early 1970s. This may result of the fleet moving to deeper water over time (hake size tends to increase with depth), as well as the

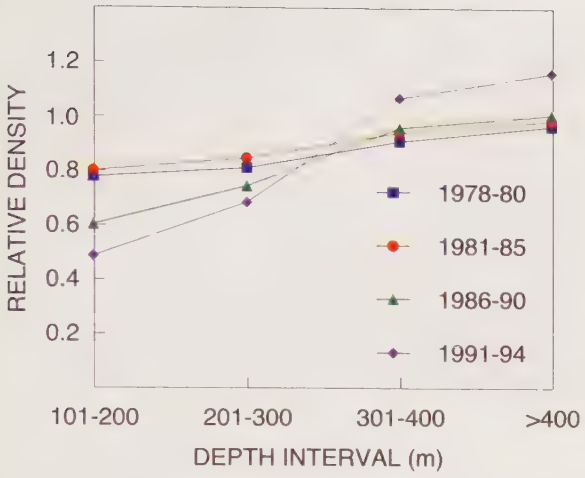

Fig. 30: Relative density of hake on the West Coast at various depth intervals over a number of sub-periods

fact that liners are no longer being used. The overall effect is that the present *cpue* reflects a smaller component of the total biomass of the resource than was the case some 15 – 20 years ago. This result explains how the total biomass of the resource, as indicated by the survey data, can have increased faster than the exploitable component of the biomass, which is indexed by the *cpue*.

Depth related seasonal changes in length frequency of Agulhas sole

Length frequency distributions of Agulhas sole were investigated for 25-m depth zones, based on data from research surveys in autumn and spring between 1990 and 1995. Sole were present in trawls down to a depth of 125 m, and average fish length increased with trawl depth. The number of sole per trawl decreased with depth (see Fig. 31), but because the deeper (50–100 m) depth zones cover greater areas than the shallower zones (<50 m), the number of sole in deeper water constitute a significant proportion of the stock. No data were available for the 0–25 m depth zone, but the presence of sole in this depth zone was inferred from the high concentrations of sole found in the 25–50 m depth zone.

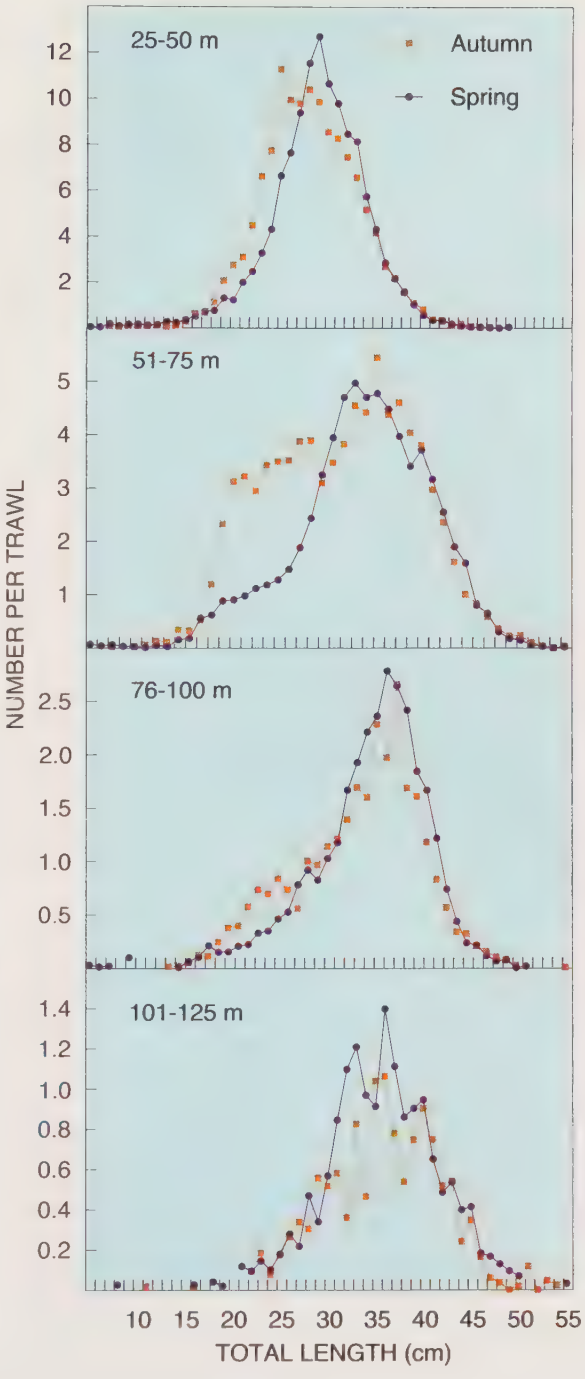

Fig. 31: Length distribution (number per trawl) of Agulhas sole for the period 1990–1995, for four depth zones

As juveniles are usually not abundant in water deeper than 25 m, it is assumed that they preferentially inhabit the zone shallower than 25 m. The distribution of juveniles and adults overlaps in water deeper than 25 m. Juveniles smaller than 25 cm were present in larger numbers in autumn than in spring, but mainly in the 25–50 m and 51–75 m depth zones. Further investigation showed that the surveys in May 1990 and June 1991 accounted for most of the large numbers of juveniles (Fig. 32). Those two autumn surveys coincided with peaks in commercial catch rates west of Cape Infanta. Autumn surveys in the other years took place either before the peaks in winter catch rates (April of 1992, and 1993) or during a period of minor increase in catch rate (June 1994) or just prior to the peak in catch rate (May 1995). Peaks in commercial catch rates coincided with periods of strongest winter winds, suggesting that juveniles may move into deeper water during winter storms. The juveniles are not present in spring, implying that they must move back into shallow water then.

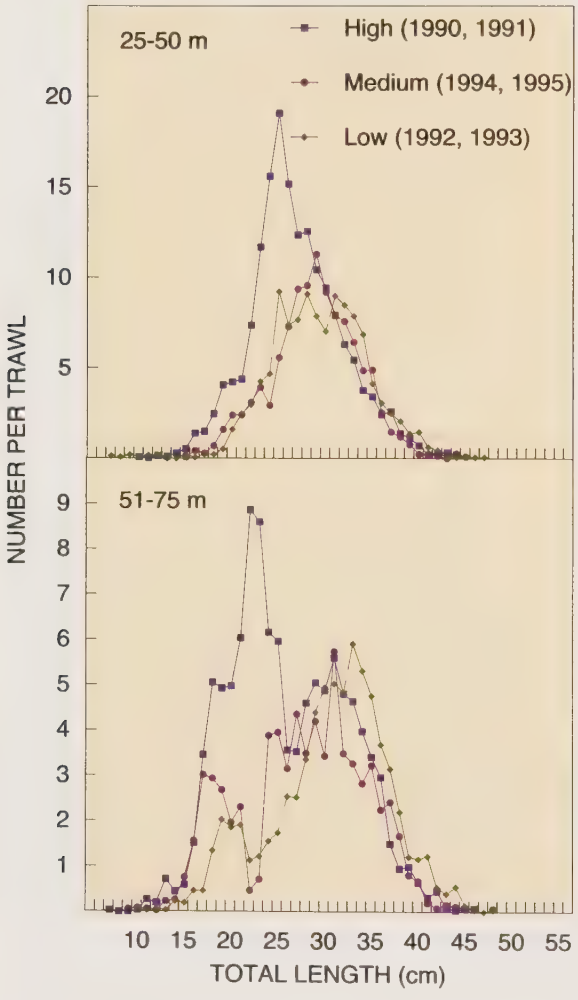

Fig. 32: Length distribution (number per trawl) of Agulhas sole for autumn surveys between 1990 and 1995 during periods of high, medium and low commercial catch rates

These results have implications for biomass estimates based on surveys. One implication is that the number of juveniles in the 0–25 m depth zone is usually underestimated because they are extrapolated from trawls made in the 25–50 m zone. Another implication is that if adults also move out of the shallow water onto the trawling grounds in deeper water, the commercial catch rates in deeper water would suddenly increase. This could explain in part the abrupt, localized, seasonal increases in commercial catch rates.

Modelling the stock dynamics of chokka squid

The chokka squid is caught by a local jig fishery, which primarily targets spawning aggregations off the South Coast, and as a by-catch in an inshore trawl fishery, which targets the Cape hakes and Agulhas sole. The jig fishery is of great importance particularly in the Eastern Cape, both as a source of income for the region and because it creates employment for a large number of people. While effort control is the chief management tool for this fishery, other management measures include a closed season and restricted areas. In spite of the existing control measures, there is concern that the resource could be overexploited given that the jig effort has been climbing continuosly since the onset of the fishery in early 1980s.

A study to assess the status and productivity of chokka was completed in 1998. The dynamics of

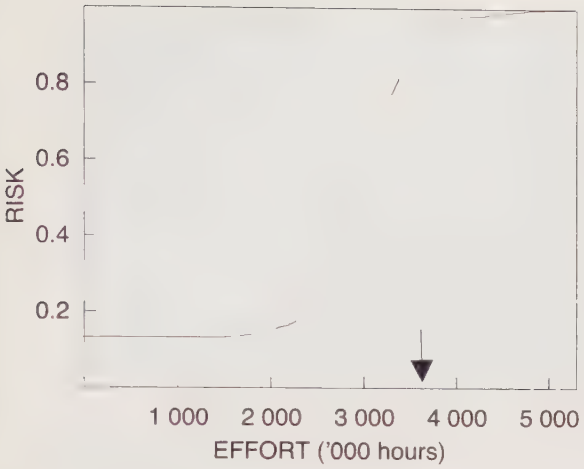

Fig. 33: Risk associated with different levels of effort, evaluated from 10-year projections. The arrow indicates current levels of effort

the stock biomass were modelled in order to assess the effects of the existing closed season and current levels of effort on the resource. *Cpue* data from the two fisheries and biomass estimates from spring and autumn research surveys were used as indicators of stock abundance. The uncertainty associated with the model estimates of current stock size and associated productivity was identified as a key element in the assessment. The risk of the spawning biomass falling below 20% of its pristine level was high compared to that of other short-lived species; even without fishing (i.e. effort = 0), risk is already 0.13 (Fig. 33). This is because the risk assessment is based on projections commencing from estimates of current biomass, which suggest that the stock is already severely depleted. Therefore, even without fishing, the resource would take a few years to recover to safer levels. Examination of Fig. 33 suggests that cutting back effort to approximately 2 400 units, about 2/3 of the existing fishing effort, could reduce the associated risk level substantially.

Responsible management of this fishery dictates that the biological risks evaluated in this study will have to be considered in conjunction with the socio-economic consequences of possible reductions in fishing effort.

Effect of effort saturation on abundance indices of lobster

There is concern that the standardized *cpue* index used for annual assessment of the South Coast rock lobster resource does not only reflect the trends in the abundance of this resource but is also influenced by changes in fishing strategy. This change in fishing strategy is illustrated by the gradual increase in the numbers of traps used per vessel in the fishery since the late 1980s (Fig. 34), when a restriction on the number of traps per vessel was removed. Most vessels now use two or more complete sets of gear, which they haul on alternate days. The increased numbers of traps on the fishing grounds is not addressed in the general linear model (GLM) used to standardize the *cpue* data, because only daily trap-hauls are recorded (now with soak-times of 48 or more hours, instead of the traditional 24 h sets).

It is therefore possible that the continual decline in the *cpue* index of 1989 to 1998 (Fig. 35) is, at least in part, a reflection of trap-saturation effects arising from the surfeit of traps now in use, instead of an accurate index of the decreasing abundance. To investigate the effect of surplus traps on the *cpue*, an effort-reduction experiment was launched as a joint venture between the M&CM scientists, the South Coast rock lobster association and their consultants. Trap-saturation on the fishing grounds was to be tested by systematically reducing (by approximately 40%), the number of traps carried by fishing vessels. An immediate increase in trap *cpue* would indicate that decreased catches per trap were the result of competition between traps.

Data collected during two treatments (full effort Dec.'98 – Jan.'99, reduced effort Feb.'99 – Mar.'99) showed an increase in *cpue* during the reduced effort treatment, after seasonal and annual effects had been accounted for. Although the increase in *cpue* during the reduced treatment was not significant, the results suggested that seasonal trends in *cpue* are also dependent on area. The experiment was consequently extended to

Fig. 34: Vessels hauling large numbers of trap

take area into account, by subdividing the fishing grounds into areas of reduced effort and full effort. The lobster fleet is currently (1999) undertaking this phase of the experiment, with reduced effort on the Agulhas Bank, and full effort between Mossel Bay and East London.

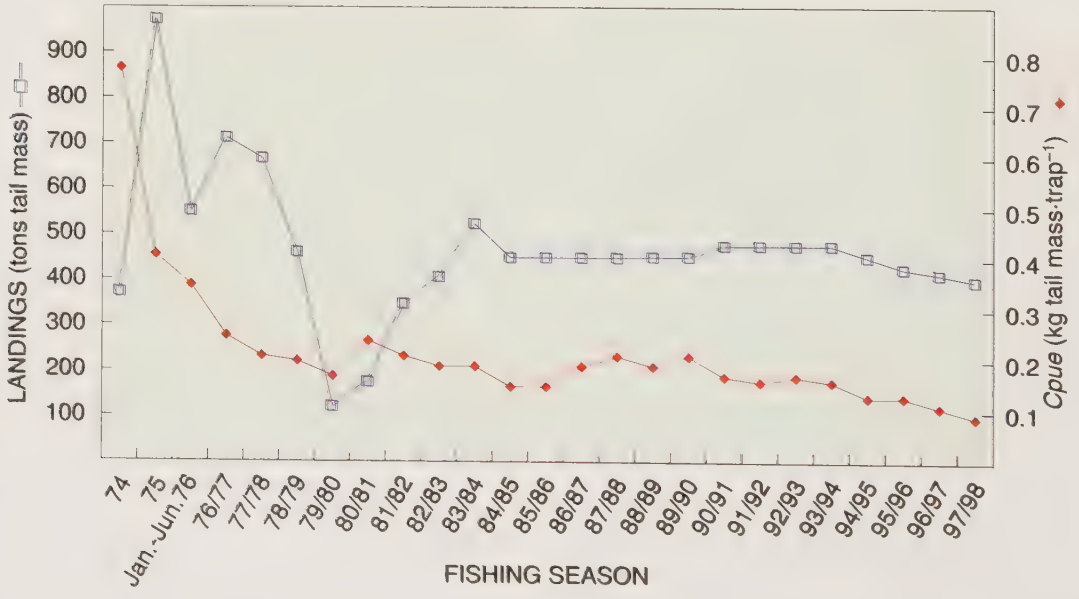

Fig. 35: Increase in effort and reduction in cpue *since 1990*

The results of the experiment are to be incorporated into the GLM used to standardise the *cpue* index prior to the resource assessment for the 1999/2000 fishing season.

Collapse of the rock lobster fisheries in the northern Benguela – a theory of environmental change

A simultaneous decline in production and yields of rock lobsters off Namaqualand and Namibia has had a severe impact on the fisheries there.The downturn in fishery yields began in the late 1950s, became more severe in the late 1960s and 1970s, and catches have never recovered since. Unfortunately, a series of changes to minimum size limits during the period of rapid decline complicated interpretation of events. However owing to the collapse of these northern sectors, the overall yield from the *Jasus lalandii* resource as a whole declined from more than16 000 tons prior to 1955 to less than 5 000 tons after the 1960s.

Lobsters on the Namaqualand and Namibian coasts are generally restricted to shallow water (often <15m, although there are seasonal variations), by the presence of oxygen-depleted shelf water. Lobster growth rates are stunted, and size at maturity of females is small. It is clear that lobster production along this approximately 740 km of highly productive coastline is being severely constrained by the presence of oxygen-depleted shelf waters. However, there is anecdotal evidence that this was not always so. Prior to the 1960s, fishermen reported good catches in depths up to 55 m off both the Namibian and Namaqualand coasts. There are also some suggestions that lobster sizes at maturity were larger then than nowadays. If correct, this would suggest that lobster growth rates declined at the time the catches declined, and that they have not recovered since. This appears to have resulted from the population being forced to occupy a much smaller, shallow-water habitat owing to the presence of oxygen-depleted bottom waters farther offshore. Density-dependent effects on lobster growth and survival, together with reduced availability to capture in a highwave-energy shallowwater environment, would appear to be severely constraining fishery yields.

Because of the large impact that low oxygen appears to have had on both sole and lobster stocks in the northern and central Benguela upwelling system, as well as possible related impacts on pelagic fish populations, ongoing research has been aimed at investigating the origin of this phenomenon and its apparent variability over time.

Current understanding is that a large increase in primary productivity must have taken place after the 1950s which caused an intensification of the production of oxygen-depleted bottom waters in the diatom-rich coastal waters of northern Namibia. These bottom waters spread southwards along the Namibian and Namaqualand coasts under the influence of a well-documented poleward undercurrent. Deposition patterns of large, chain-forming diatom species in coastal sediments within the so-called diatomaceous mud belt between 19 and 25°S off the Namibian coast point towards loci of nutrient enrichment unrelated to simple wind-induced upwelling. These centres of nutrient enrichment are located nearshore, adjacent to the points where seven major underground river systems meet the coast, suggesting that seepage of subterranean groundwaters from the ephemeral rivers draining the western escarpment is the key to the enhanced productivity. Chemical analyses of subterranean groundwater display exceedingly high levels of dissolved silicate, a key nutrient for diatom production.

Recent analysis of rainfall patterns in the river catchments draining the region 19–25°S has illustrated that a marked change in rainfall patterns commenced during the 1960s, with increased rainfall in all catchments during the late 1960s and throughout the 1970s, followed by lower levels during the 1980s and 1990s. The inference is that a nutrient-driven change in ecosystem productivity commenced during the 1960s, coincident with a collapse of the West Coast pilchard

stock and its replacement by anchovy and pelagic goby *Sufflogobius bibarbatus*, a change that was also accompanied by an intensification of the production of oxygen- depleted bottom waters.

The lack of recovery, to date, of the Namibian and Namaqualand lobster stocks gives credence to the idea that the system has not reverted to its earlier, apparently less-productive phase, implying that silicate recycling over the siliceous mudbelt in the region 19-25°S may be maintaining the system in hypertrophic mode, with persistently high levels of diatom production and decay, and southward advection of oxygen-depleted bottom water.

The same phenomenon, i.e. the predominance of large, chain-forming diatoms in the coastal waters of the region 19–25°S may also prove to be a primary factor in maintaining the dominance of anchovy and pelagic goby in the northern ecosystem, and preventing a resurgence of the northern pilchard stock that was so abundant prior to the 1960s. Experimental work is needed to test this possibility.

Comparative spawning habitats of anchovy and sardine in the southern Benguela

Data on the abundance and distribution of the eggs of anchovy *Engraulis capensis* and sardine *Sardinops sagax* have been collected since 1984 during the annual pelagic spawner biomass surveys. This dataset has permitted a comparison of the spatial distinction of the spawning habitats of the two species and an assessment of whether their selected habitats differ with respect to sea surface temperature (SST). Although both anchovy and sardine spawn during spring/summer, they show a temporal separation in the timing of peak spawning; anchovy have a single spawning peak in October–December, whereas sardine have two spawning peaks (September/October and February/March). Although the spawner biomass cruises are timed so as to survey during peak anchovy spawning, sufficient data concerning the distribution of sardine eggs have been collected to permit a detailed analysis of spawning habitats.

The spatial distribution of these eggs was analysed by calculating the percentage of eggs in five different predetermined areas or categories of continental shelf strata. This allowed the relative importance of each stratum as a spawning site to be assessed from year to year. Anchovy egg distributions were most spatially stable through time and showed consistent spawning east of Cape Point (Fig. 36). Although 30-40% of anchovy eggs were found west of Cape Point during the period 1986–1988, the Agulhas Bank was the principal spawning ground of anchovy during the rest of the time-series, with areas of intense spawning on the Agulhas Bank differing from year to year. In contrast, sardine eggs were more patchily distributed through time, with both West and South coasts being the major spawning grounds in different periods. Despite the more patchy distribution of sardine than anchovy eggs, both have shown a broad-scale overlap for most of the time-series. In recent years, however, the spawning areas of anchovy and sardine have become markedly distinct, with anchovy spawning principally off the South and East coasts, and sardine spawning predominantly off the West Coast. More than 80% of anchovy eggs have been found east of Cape Point during each survey since 1994, with most eggs being found over the central and eastern Agulhas Banks. This eastward shift in anchovy egg distributions is linked to changes in the anchovy population structure observed recently: poor recruitment over the past few years has resulted in older fish constituting a larger proportion of the population. In addition to moving eastwards with age, older anchovy make a disproportionately large contribution to spawning. In contrast, at least 65% of sardine eggs have been found west of Cape Point during the past five years. Patterns of sardine egg distribution now resemble those observed during the 1950s and 1960s, a time when sardine biomass was high.

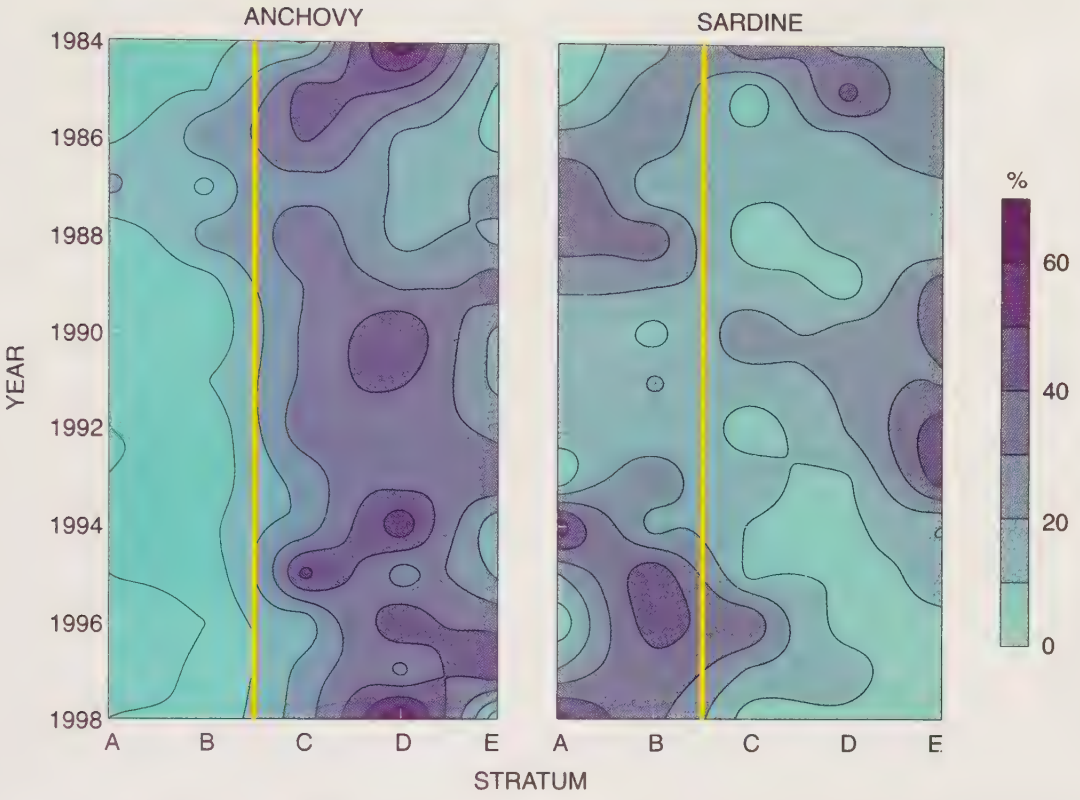

Fig. 36: Changes in the patterns of abundance and distribution of eggs through time for anchovy and sardine. The x- axis represents the coastline, which has been "straightened" and divided into 5 strata (Stratum A on the West Coast and Stratum E on the South Coast), and the y-axis represents time. The percentage contribution to total egg abundance during the survey is shown for each of 5 strata by year, and contouring is used to interpolate between years and strata. Stratum A is the West Coast, extending north of Cape Columbine; Stratum B is the South-West Coast, extending from Cape Point to Cape Columbine; Stratum C is the Western Agulhas Bank, extending from Cape Agulhas to Cape Point; Stratum D is the Central Agulhas Bank, extending from Cape St Blaize to Cape Agulhas; Stratum E is the Eastern Agulhas Bank, extending eastwards from Cape St Blaize. The vertical yellow line indicates the approximate position of Cape Point.

In order to assess the preferred SST range for spawning for each species, the number of eggs found in each SST class was expressed as a percentage of all eggs collected. This value was then divided by the percentage frequency of occurrence of that particular SST class. The resultant quotient value reflects the selection of spawning habitat by temperature, or by any other factors associated with such temperature ranges. Assuming that fish do in fact select spawning habitat on the basis of SST, quotient values of >1 indicate positive selection, whereas values of <1 indicate that fish avoid spawning at that SST. When the data from all CalVET net hauls during the time-series are combined it becomes apparent that sardine spawn over a wider temperature range than anchovy, and that anchovy spawn in warmer waters than sardine (Fig. 37). Anchovy show quotient values >1 for temperatures between 17.4 and 21.1%C, whereas sardine show quotient values >1 at 15.2–18.2, 19.4–19.8, and 20.2–20.5%C. This temperature difference between the two species reflects the spatial differences in anchovy and sardine

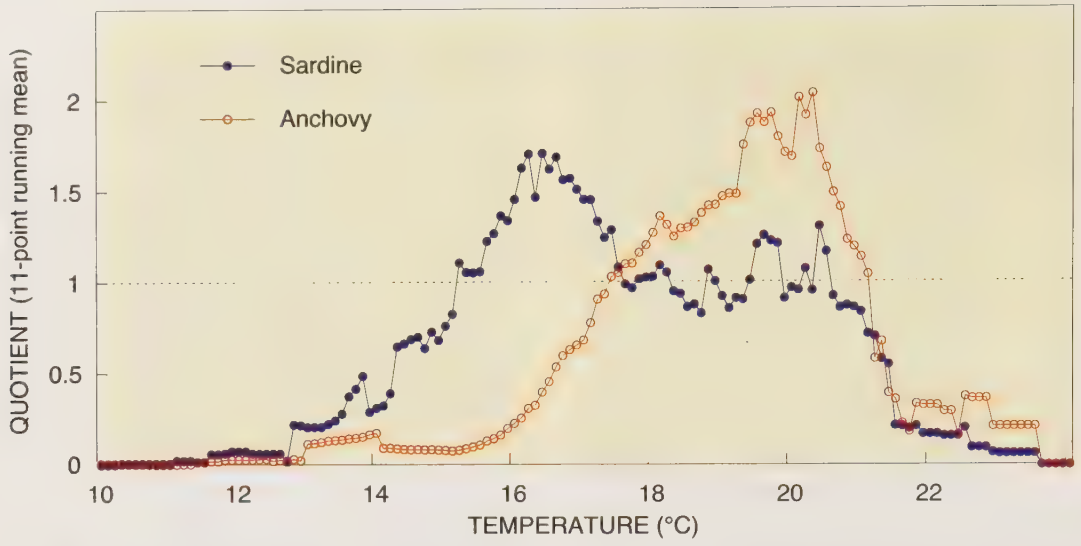

Fig. 37: Egg abundance/temperature quotients (the 11-point running means are shown) for anchovy and sardine egg samples collected during November surveys, 1984–1998

spawning habitat discussed above. However, it also suggests that anchovy will spawn farther offshore than sardine in regions where they co-occur during the spawning period, because SST during summer shows strong cross-shelf gradients.

Forecasting the recruitment strength of anchovy in the southern Benguela

Reliable forecasts of the recruitment strength of anchovy in the southern Benguela at the start of each fishing season may contribute significantly towards more efficient utilization of the resource by the pelagic fishing industry. In the absence of long-term data and a strong stock-recruit relationship, and as a result of large interannual fluctuations in recruitment strength, sources of information other than the stock assessment/fisheries data could assist in obtaining forecasts of recruitment.

Over the past decade, the environmental conditions in the dominant spawning and recruitment areas of anchovy have been monitored intensively during the annual hydroacoustic surveys of the spawner and recruit stocks, and during monthly cruises covering the spawning seasons of 1993/94 and 1994/95. The overall goal of these studies was to investigate environmental factors affecting anchovy recruitment and to try to develop an ability to forecast anchovy recruitment from year to year using field data obtained during the spawning season (August – March).

During recent studies, the environmental data and additional biological data have been used to develop deterministic expert systems to forecast anchovy recruitment. These expert systems incorporate a set of rules linking anchovy recruitment to selected biological and environmental variables. The models are used to obtain a qualitative forecast of below-average recruitment (BAR). To date, six indicator variables have been considered in the analyses: distance offshore of the 16°C isotherm; southerly wind stress; anchovy egg abundance; incidence of oocyte atresia in adult female anchovy; indices of fish starvation; and oil:meal ratios obtained from commercial catch data (which are used as an index of fish condition). Data for each variable are assessed against a threshold value (see Table 4). Variables are assumed active when they contribute

Table 4: Indicators used and their threshold values.

Variable	Threshold
Index of wind stress (Southerly wind anomaly)	1 667 km cumulative S. windrun
Distance offshore of the 16°C isotherm at 33°S	26 nautical miles
% Starvation stations on the Agulhas Bank	30 %
% females with oocyte atresia	10 %
Daily egg production	300 eggs·m^{-2}
Monthly (commercial) oil:meal ratio	1.7% oil

towards BAR by being either above or below their threshold values. A summary of the rules used to forecast recruitment is presented in Table 5.

Table 5: Summary of the rules used for forecasting recruitment

- If there are no active indicators, then "average/above-average recruitment" will be forecast
- As soon as there are active indicators, however, a chance (however small) exists for "below-average recruitment", and as such:
  - ▲ if the number of active indicators is one-third (33%) or less of the total number of indicators used in the forecast, "possible below-average recruitment" will be forecast;
  - ▲ if the number of active indicators lies between one- and two-thirds (33 – 66%) of the total number of indicators used in the forecast, "likely below-average recruitment" will be forecast;
  - ▲ if the number of active indicators is greater than two-thirds of the total number of indicators used in the forecast, "very likely below-average recruitment" will be forecast.

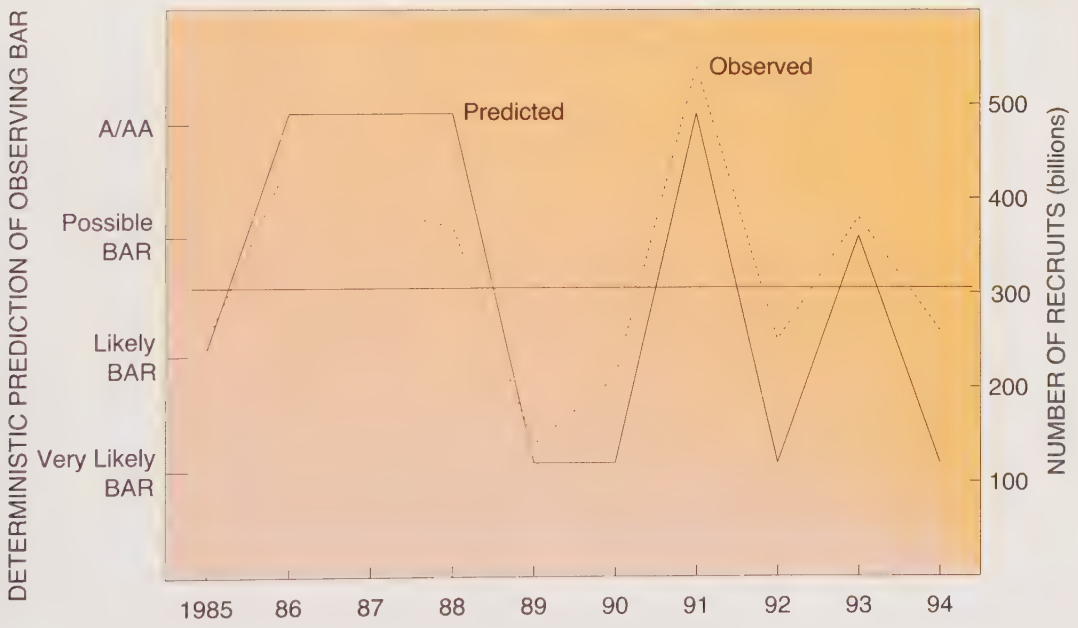

Fig. 38: Comparison of observed and predicted anchovy recruitment obtained from the deterministic rule-based expert system. BAR = below-average recruitment, A/AA = average/above-average recruitment. The long-term average for anchovy recruitment strength (302 billion fish) is shown.

Forecasts from simple deterministic expert systems compare favourably with observed recruitment for the time series used to construct the expert system (Fig. 38). Results from these studies suggest that field measurements of environmental and biological variables may be used in a structured way to obtain forecasts of anchovy recruitment to the fishery.

Ecosystem effects of fishing

By means of an ECOPATH model, trophic flows through the southern Benguela ecosystem were modelled for the period 1980–1989. ECOSIM, the new dynamic module of ECOPATH, was used to simulate effects of altered fishing strategies of the three most abundant small pelagic fish species (anchovy, sardine and round herring) as well as commercially important hake. Altered fishing scenarios investigated were:

- increased fishing mortality F of anchovy, sardine and round herring fourfold from year 10 onwards (Fig. 39a);
- increased fishing mortality of anchovy, sardine and round herring fourfold from year 10 to year 15, thereafter F restored to original levels (Fig. 39b);
- increased fishing mortality of hake fourfold from year 10 to year 15, thereafter F restored to original levels (Fig. 39c).

Three types of "flow control" modelled the way in which ecosystem components interact:

- bottom-up control of predators by zooplankton prey (*bottom-up control*);
- neither top-down nor bottom-up control (*mixed control*);
- top-down control of zooplankton by small pelagic fish and bottom-up control of predators (predatory pelagic fish, seabirds and marine mammals) by small pelagic fish (*wasp-waist control*).

When there was bottom-up control, modelled effects of altered fishing strategies were small and dampened (Fig. 39). This resulted from intense competition between species eating zooplankton. However, when wasp-waist control was assumed, there was not intense competition for zooplankton food, and the ecosystem components responded more readily to changes in fishing pressures, so that major perturbations propagated through the system and components recovered more slowly (Fig. 39). Modelling interactions of the mixed control type gave results intermediate between the other two control types.

When fishing mortality on the three small pelagic fish was increased fourfold, anchovy and sardine stocks collapsed (Fig. 39a). When there was bottom-up control, anchovy biomass stabilized at about half that at the start, and sardine stabilized at 40% of its original biomass. Modelled populations of predators stabilized at smaller sizes, whereas those competing for food with anchovy and sardine stabilized at larger population sizes than were maintained before increased fishing. When there was wasp-waist control, large pelagic fish were reduced to a stable level at 43% of the group's original biomass, whereas modelled abundance decreased steadily under mixed control (Fig. 39a).

Modelling a pulsed increase in fishing of the three small pelagic fish showed that, for bottom-up control, all components recovered fully within 10 years of return to normal fishing levels (Fig. 39b). System components took longer to recover when flow control was mixed, and for wasp-waist control, many groups had not returned to original biomass levels by the end of the simulation (Fig 39b).

Heavy fishing of hake reduced its biomass and favoured some of its prey species, such as mesopelagic fish and squid (Fig. 39c). Horse mackerel were negatively affected by the increased biomass of mesopelagic fish, which competed with them for zooplankton food. For bottom-up and mixed control scenarios respectively, all groups recovered within 10 and 20 years of return to normal fishing. Under wasp-waist control, perturbations were larger and many groups had not returned to original levels by year 50.

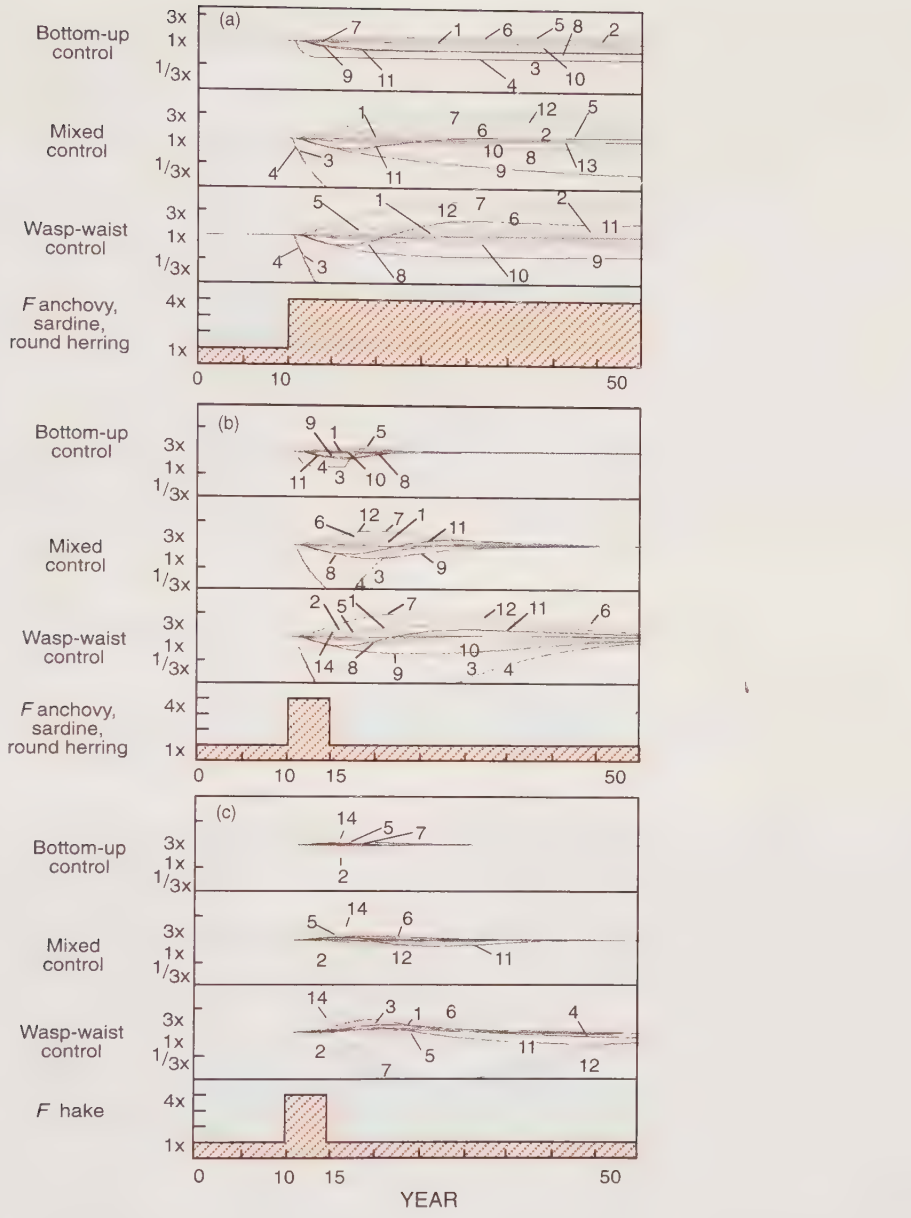

Fig. 39: Effects of a fourfold increase in fishing mortality F of anchovy, sardine and round herring a) year 10 onwards; b) year 10 to 15, after which F is restored to original levels (bottom panel); c) F of hake from year 10 to 15, after which F is restored to original levels. Biomass is plotted as a proportion of original biomass.

The study showed that modelled ecosystem effects of fishing are largely determined by the way in which interactions between components of an ecosystem are presumed to be linked. Results differed for different selections of top-down and bottom-up control between selected groups. For example, increasing fishing mortality of anchovy and sardine fourfold was sustainable under bottom-up control by zooplankton, and stocks stabilized at lower levels. By contrast, assuming mixed or wasp-waist control caused a collapse of anchovy and sardine fisheries and stocks. Understanding the way in which an ecosystem functions in terms of internal control between its components will be the key to predicting ecosystem effects of fishing.

Movement patterns of inshore fish

Fish require sanctuaries for their natural breeding habits to persist, undisturbed by the relentless removal of large spawning adults by fishers. Many populations have natural refuges where fishers can not access them, but modern technology is quickly eroding these away. The response of management could be to impose sanctuaries, but how many should there be, and of what size? The answer to these questions is a trade-off between fishing pressure, stock productivity and fish dispersal (poorly known for most species). The last of these is the subject of recent research. A marine protected area (MPA) should be large enough to contain wild fish, but not so large that it withholds an unnecessarily large portion of the fish population from the fishery.

Fish movements are studied by tagging. A recovered tag yields two positions that a fish occupied in its life; by itself not very instructive but, when hundreds of these data are examined together, persistent patterns emerge. Clear patterns can be described for galjoen *Dichistius capensis* (Fig. 40), blacktail *Diplodus sargus capensis*, white steenbras *Lithognathus lithognathus* and carpenter *Argyrozona argyrozona*, while for others such as the kob species *Argyrosomus* spp. (Fig. 41), musselcracker and spotted gulley

Fig. 40: Tagged galjoen have shown a curious split between residency and long distance movements

Fig. 41: Dusky kob appear to remain within a large home range

shark *Triakis megalopterus*, research is still in progress.

All the basic types of dispersal patterns are evident among our coastal fish. The resident pattern, in which fish remain within a tightly defined home range, is one of the more common. Blacktail is an example of a resident fish species. Of the 137 recoveries of blacktail tagged in De Hoop MPA, only one had moved an appreciable distance (>3 km), most being recovered close to the release site. Some resident fish, such as Roman *Chrysoblephus laticeps*, may display territorial behaviour, if the large adults defend territories. Such behaviour tends to spread the population evenly over suitable habitat.

Complications to the residency pattern arise if most fish are recovered in the same place, but some are recovered considerable distances away. Juvenile white steenbras are resident in a large home range, but the adults (length >800 mm) are known to migrate to the Wild Coast to spawn every year, and then to return to the Cape. This is an adaptation to prevailing currents, which are probably used to distribute the larvae to suitable settlement grounds in the Eastern and Western Cape. Galjoen show a consistent, but confusing, pattern. Approximately 80% of galjoen recoveries have been at the site of release, whereas the remainder ere displaced throughout the population, some moving distances of more than 1 000 km. The distinction is not linked to sex or season, but is more likely to reflect a population of individualistic fish that move between a few localized feeding sites throughout their lives. Fine-scale spatial resolution of recoveries reveals that approximately 50% of the recovered galjoen had not moved 100 m (despite times at liberty of several years), and another 30% remained within 500 m of the release site. These figures are of significance for the design of MPAs.

The pattern displayed by galjoen is not uncommon, and several others seem to display slight variations of it. Spotted gulley sharks are usually caught within 100 m of the release site, but a small percentage have moved considerable distances. Carpenter are highly resident, being recovered on the same reef pinnacles on which they were released in Tsitsikamma National Park. However, echo-sounding and diving surveys frequently reveal a total absence of carpenter on the reefs. Where were they in the interim? And why do they return to the same reef? The reasons may be difficult to find, but the implications are clear. Small MPAs can be very effective for fish conservation.

Many piscivorous species have been regarded as migrants (fish whose movements are predictable in time and space). Elf *Pomatomus saltatrix* is the classic example of a species that moves between rich summer and winter feeding grounds. However dusky kob *Argyrosomus japonicus* are more puzzling. Of 18 recoveries of dusky kob released in De Hoop MPA, four had moved outside the reserve into the Breede River, whereas nine were recovered within a few hundred metres of the release site. This may indicate a large home range, but it does not preclude the possibility of adult spawning migrations.

These data are being applied to models, first to help resolve the movement pattern and second to provide indications of the value of MPAs for fish conservation. For this purpose, conventional population based models, models in which the population is represented by a number (of fish), may not be as useful as individual-based modes, in which the trajectory of each fish is accounted for. Fish are, after all, as individualistic as our own species!

Brown tides in Saldanha Bay

In January 1997 an oyster farmer in Saldanha Bay complained of discoloured water and reduced growth rates of oysters. The inspection of water samples revealed a bloom of minute (2–3 m), coccoid, non-motile cells. The following year the bloom again appeared during the latter half of summer and, on that occasion, the entire Saldanha Bay and Langebaan Lagoon turned a very unusual and distinct golden brown, a colour that persisted for 6–8 weeks. Surface water samples collected during March 1998 from several localities within the Bay and Lagoon indicated unprecedented concentrations of these coccoid cells of $10^9 \cdot \ell^{-1}$ and corresponding chlorophyll *a* levels ranging from 21.3–41.0 mg· m^{-3}.

Collaborative studies undertaken at the University of the Witwatersrand using transmission electron microscopy have revealed the identity of this organism to be the chrysophyte *Aureococcus anophagefferens* (Fig. 42). This picoplankter was first described in 1988 after very similar blooms

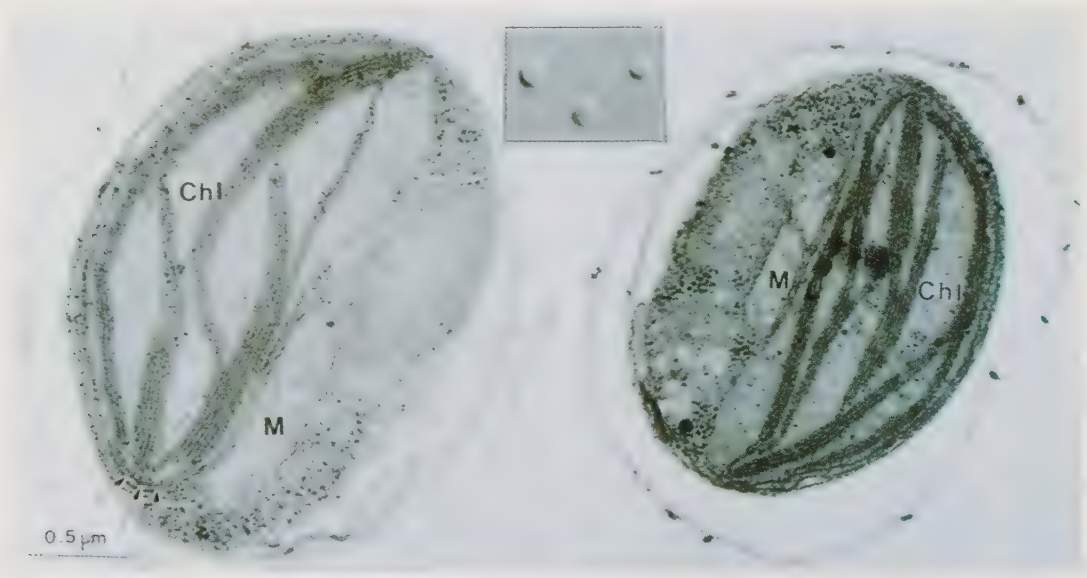

Fig. 42: The bloom alga, Aureococcus anophagefferens, *as shown by transmission electron micrographs of thin sections of the natural population. A typical cross section through a cell shows a chloroplast, a mitochondrion and nucleus*

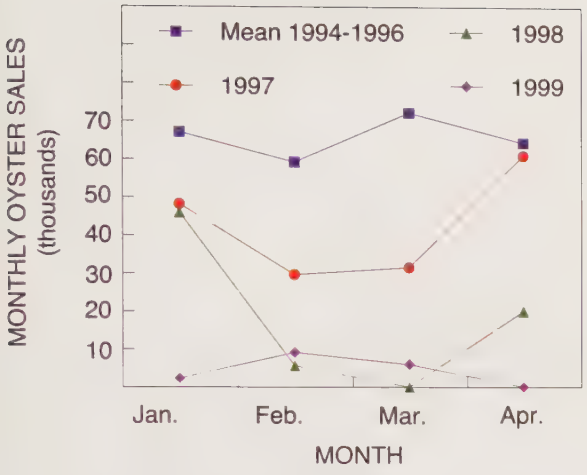

Fig. 43: Recent oyster sale figures for the months January to April from the farm Seafarms

(aptly named "brown tides") impacted coastal embayments along the mid-Atlantic coast of the United States during the mid 1980s. Since then these blooms have occurred annually there, and have had several detrimental effects, including a crippling effect on the scallop industry. A dramatic decline in scallop landings has coincided with the occurrence of these blooms, the result of a cessation of feeding. The Saldanha Bay observations represent the only other account of this bloom organism outside the United States.

In Saldanha Bay the bloom has been centred on the oyster farm *Seafarms*, a small water space isolated from the larger Bay system by a causeway, with a single pipeline providing limited tidal exchange. The *Aureococcus* bloom reappeared at the same farm in late 1998 and persisted through the summer of 1999; it now threatens the continuation of oyster farming there. Oyster harvest figures from *Seafarms* clearly depict the impact of this bloom on oyster growth (Fig. 43). The oyster farm operates by sorting and harvesting oysters >50 g throughout the year. Prior to 1997, monthly sales for the period January – April typically exceeded 50 000 oysters. Subsequent to the appearance of the *Aureococcus* blooms in 1997, monthly sales declined dramatically and, in 1999, have not exceeded 10 000 oysters. In addition to the impact on oyster growers, mussel farmers in Small Bay, Saldanha Bay, were also negatively affected, particularly in 1998. Instead of obtaining typical yields in excess of 70 kg per rope for that time of the year, the yield of market-size mussels in March 1998 dropped to about 20 kg per rope.

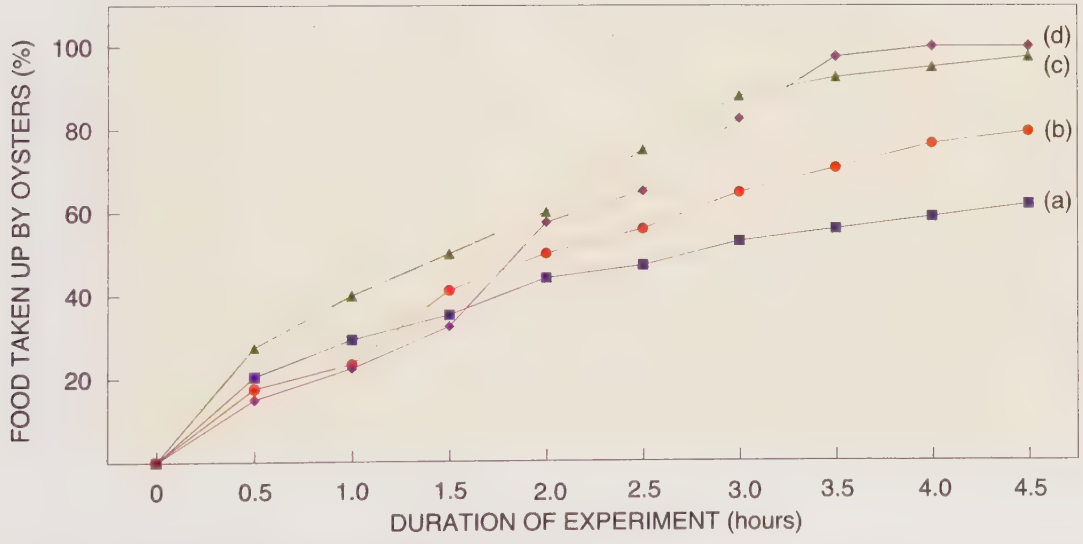

Fig. 44: Food uptake by large (a+c) and small (b+d) oysters placed in Aureococcus*-dominated (a+b) and diatom dominated water (c+d)*

Mussels also developed an uncharacteristic ridge on the shell during the period of the bloom, indicating growth arrest. The possibility exists that the *Seafarms* site now acts as a refuge seed stock that can at times invade the whole Bay system.

There has been some debate as to whether bivalve grazing is inhibited merely as a consequence of the small size of the bloom organism or as a result of the production of toxic or at least inhibitory substances on the cell surface of *Aureococcus*. Feeding experiments conducted with oysters from *Seafarms* confirmed that feeding on the *Aureococcus* bloom, particularly by large oysters, was inefficient. However, the same oysters were able to feed more efficiently when placed in water from outside the Bay and dominated by a diatom bloom (Fig. 44).

Studies in Long Island Sound, which has for some time experienced severe and prolonged blooms of *Aureococcus*, suggest that its ability to utilize organic nitrogen efficiently, particularly as urea, provides a physiological basis for its success under conditions of low inorganic (NH_4 and NO_3) availability. Some strains of *Aureococccus*, in fact, are unable to utilize NO_3 for growth. Nitrogen uptake experiments conducted with the local species provide some interesting comparisons with these studies. Both NO_3 and NH_4 were taken up by *Aureococcus* at rates that could be adequately described by Michaelis-Menten kinetics (fitted curves in Fig. 45). It is clear that NH_4 is utilized more efficiently than NO_3 (initial slopes at low concentrations) and with a greater capacity (asymptotic maximum uptake rates). Urea was also taken up by *Aureococcus*, but in a complicated fashion, suggesting inhibition at high concentrations. Additional studies have revealed that urea uptake is inducible over time, with the effect that this suppression is ameliorated under conditions of prolonged exposure to high concentrations of ured.

The fact that *Aureococcus* is physiologically better equipped to exploit reduced nitrogen such as NH_4 and urea rather than NO_3 confers a competitive advantage under conditions of restricted physical input of NO_3 such as at this oyster-culture site. Local recycling processes such as excretion and decomposition, in making reduced nitrogen available, would serve to maintain the bloom in

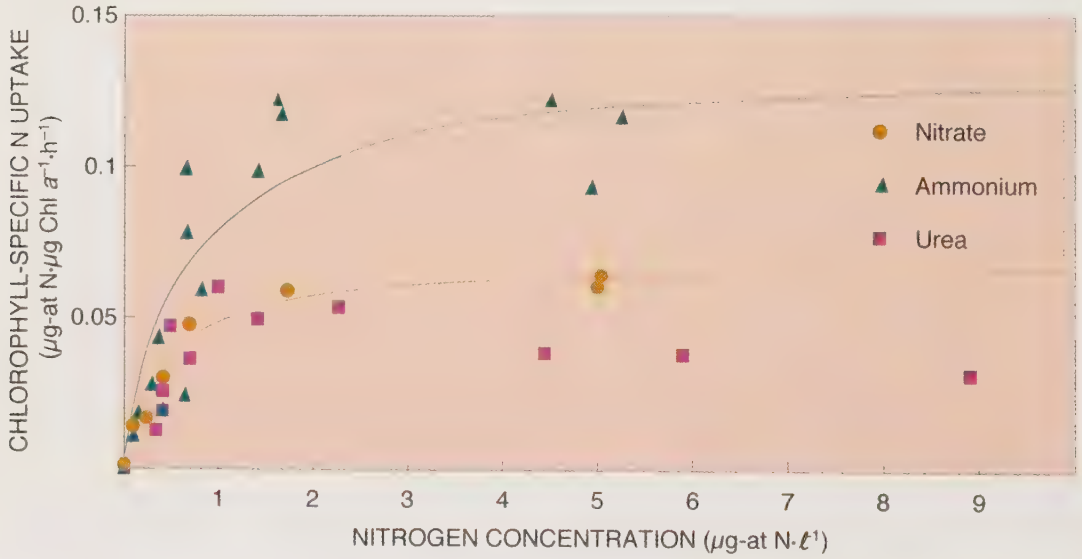

Fig. 45: Ammonium, nitrate and urea uptake by Aureococcus*-dominated populations at varying substrate concentrations. The ammonium and nitrate data were fitted to the Michaelis-Menten expression (solid curves)*

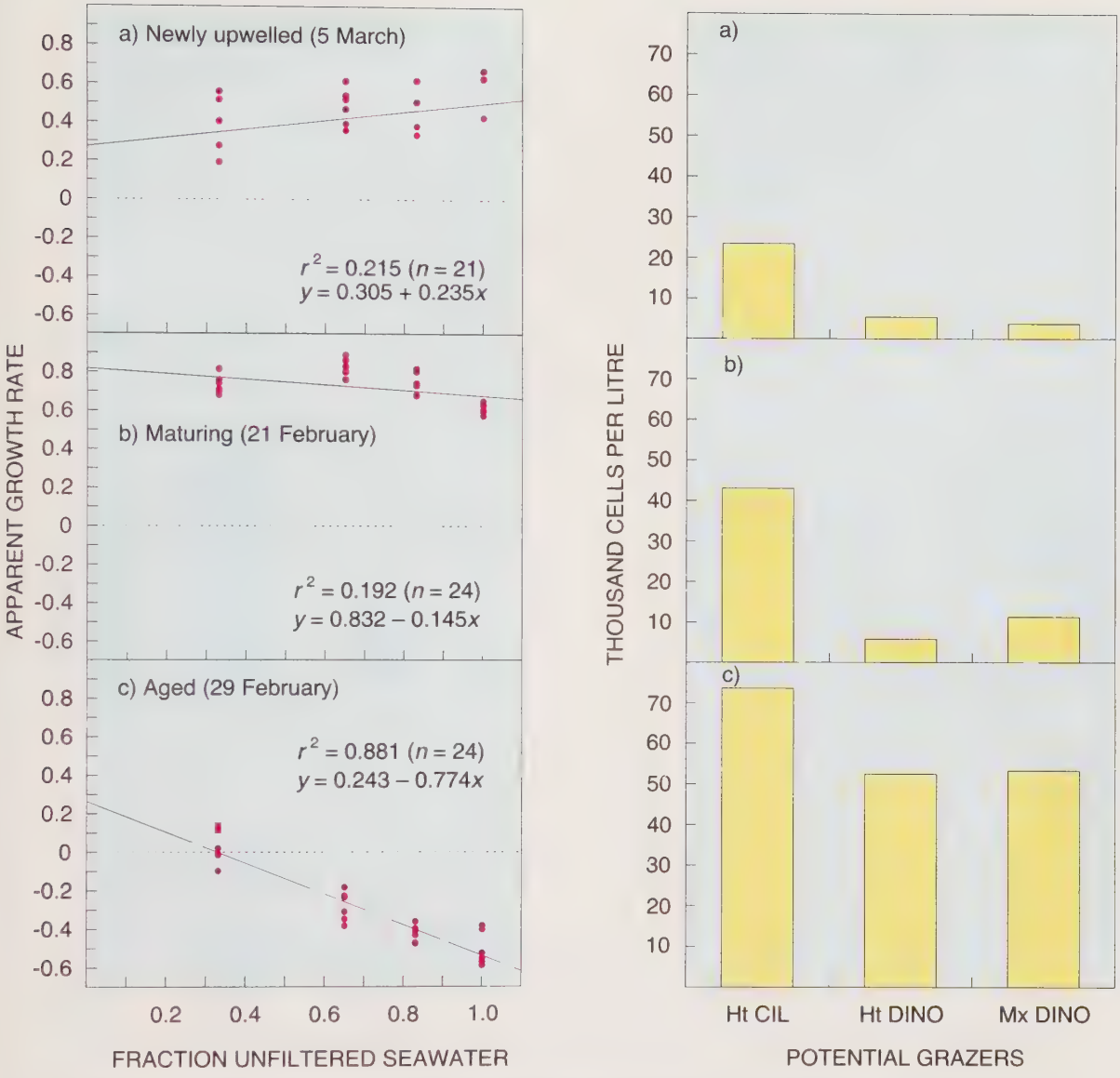
a) Newly upwelled (5 March)
$r^2 = 0.215$ ($n = 21$)
$y = 0.305 + 0.235x$
b) Maturing (21 February)
$r^2 = 0.192$ ($n = 24$)
$y = 0.832 - 0.145x$
c) Aged (29 February)
$r^2 = 0.881$ ($n = 24$)
$y = 0.243 - 0.774x$
APPARENT GROWTH RATE
FRACTION UNFILTERED SEAWATER
THOUSAND CELLS PER LITRE
Ht CIL
Ht DINO
Mx DINO
POTENTIAL GRAZERS

Fig. 46: Results of in situ *protistan grazing experiments (left panel) and the abundance of potential protistan grazers (right panel) under (a) newly, (b) maturing, and (c) aged upwelled water conditions. The slope of the relationships (left) is the instantaneous coefficient of grazing mortality, and the y-intercept is the apparent growth rate of the phytoplankton. Ht = heterotrophic; Mx = mixotrophic; CIL = ciliates; DINO = dinoflagellates*

the system. *Aureococcus* has the added advantage of a size-based refuge from heavy grazing pressure and sinking losses that act in concert to extend the duration of blooms. External inputs of reduced nitrogen (pollution) would compound the problem.

Possible mitigation measures include identifying and reducing pollution to the culture site and increasing exchange with the larger Bay system through additional pipelines or culverts. Additional physical water exchange would serve both to promote flushing of the site and to

stimulate NO_3 supply during mixed conditions in the Bay. Increased NO_3 availability would act to reduce the competitive advantage of *Aureococcus* over other phytoplankton species. However, the fact that *Aureococcus* can dominate the whole Bay system, such as in 1998, to a large extent compromises this water exchange hypothesis for *Seafarms*.

Grazing by zooplankton on red tides on the West Coast

Planktonic grazers have often been considered to play an important role in phytoplankton bloom dynamics. However, remarkably little is known about their role in the dynamics of harmful algal bloom (HAB) species, especially regarding effects on bloom initiation, development and persistence. The importance of such grazing in the ecology of HABs becomes most apparent by its failure, because, if grazing were to prevent bloom development the importance of grazing would go unnoticed.

During a one-month study of red tide in Lambert's Bay in February/March 1996, zooplankton grazing experiments were carried out to address three basic questions. First, are the dinoflagellates responsible for red tides being grazed upon? Second, if so, to what extent does grazing occur, and by which components (protists, metazoans) of the grazer community? Lastly, does grazing pressure vary through bloom development?

Water column conditions during the different experiments were characteristic of three phases of the upwelling cycle, identified by the presence of newly upwelled, maturing and aged upwelled water. Grazing by protists was determined *in situ* using a series of dilutions of natural seawater (Fig. 46). Concomitantly, grazing by metazoan zooplankton was assessed from the disappearance of species-specific phytoplankton cells using *in situ* bottle incubations with individual adult female copepods (*Calanoides carinatus* and *Centropages brachiatus*) as grazers (Fig. 47).

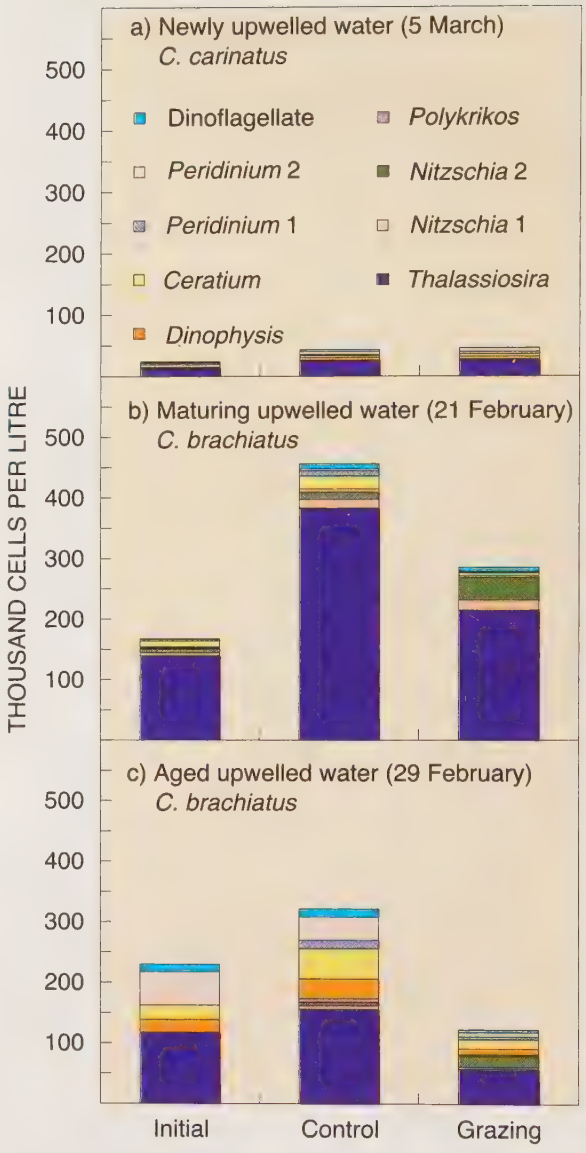

Fig. 47: Results of in situ *metazoan grazing experiments under (a) newly, (b) maturing, and (c) aged upwelled water conditions. Adult females of* Calanoides carinatus *were used as grazers in (a), and of* Centropages brachiatus *in (b) and (c). Differences observed between control and initial phytoplankton densities are attributable to growth, natural mortality and/or protistan grazing mortality. Differences between control (without grazer) and experimental (with grazer) densities are owing to metazoan grazing mortality, assuming that other sources of mortality are the same in both*

The dinoflagellates responsible for red tides were grazed upon by both protists and metazoans to variable degrees. Besides possible effects of, *inter alia*, palatability (including toxicity) and/or nutritional adequacy of food items, selective preferences of the grazers and allometric considerations, this variability in grazing pressure depended largely upon the state of upwelling, which dictates the dynamics of red tide blooms.

At the beginning of the upwelling cycle (Figs 46a and 47a), when phytoplankton growth was moderate, both the grazers and their food organisms were scarce. No marked effects of grazing were evident. In fact, a so-called "threshold feeding response" was observed in both grazer communities. Such an energy-optimizing response of reduced feeding occurs when ambient food levels are too low to elicit an appreciable grazing effort, if any at all, in grazers.

As the upwelled water matured (Figs 46b and 47b), growth of the diatom-dominated phytoplankton assemblage increased substantially, reaching maximal rates. Although increased grazing by protists and copepods was evident, it remained relatively low. Interestingly, the omnivorous copepod *C. brachiatus* appeared to supplement its diatom diet (mainly *Thalassiosira*) by also removing substantial quantities (50–94% in terms of cell numbers) of the far less abundant small-dinoflagellate community (including the small toxic *Dinophysis acuminata*).

Under aged bloom conditions (Figs 46c and 47c), when phytoplankton growth had declined to a minimal rate, populations of protistan and metazoan grazers had attained high levels of abundance. Their grazing reached maximal rates, impacting severely on the dinoflagellate-dominated phytoplankton assemblage. Indeed, whereas *C. brachiatus* removed about 60% of the *Thalassiosira* population, substantial quantities (56–82%) of the dominant dinoflagellate community were also grazed. This included the very large heterotrophic *Polykrikos schwartzii* among other, much smaller, species.

The results of these experiments, the first of their kind conducted on red tides in an upwelling system, suggest that reduced zooplankton community grazing pressure by both protists and metazoans, as a result of a temporal mismatch between grazers and phytoplankton, may contribute to the successful initiation and further development of blooms. However, once grazer populations become well established, their grazing may have a potentially substantial impact on the persistence of red tide blooms. Further studies of interactions between naturally co-occurring

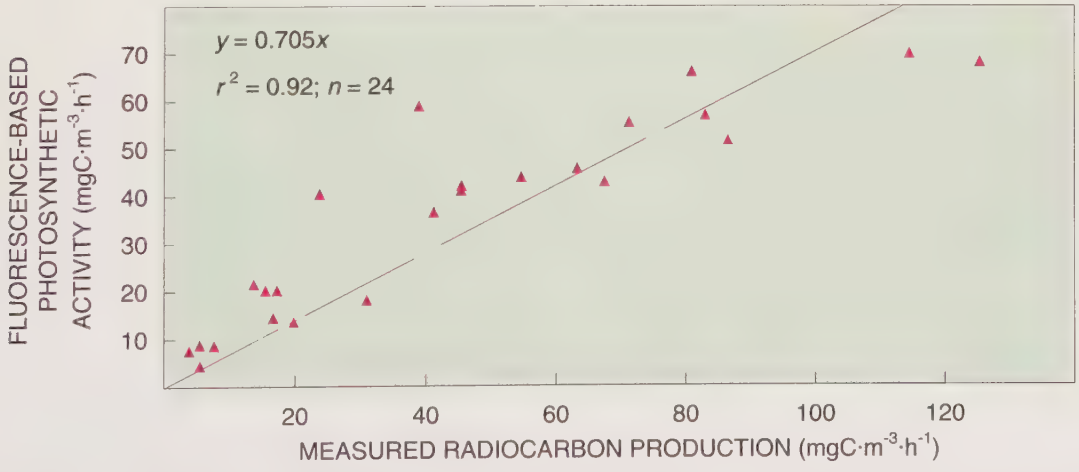

Fig. 48: Comparison between natural fluorescence-based measurements and radiocarbon (^{14}C) measurements of photosynthetic activity

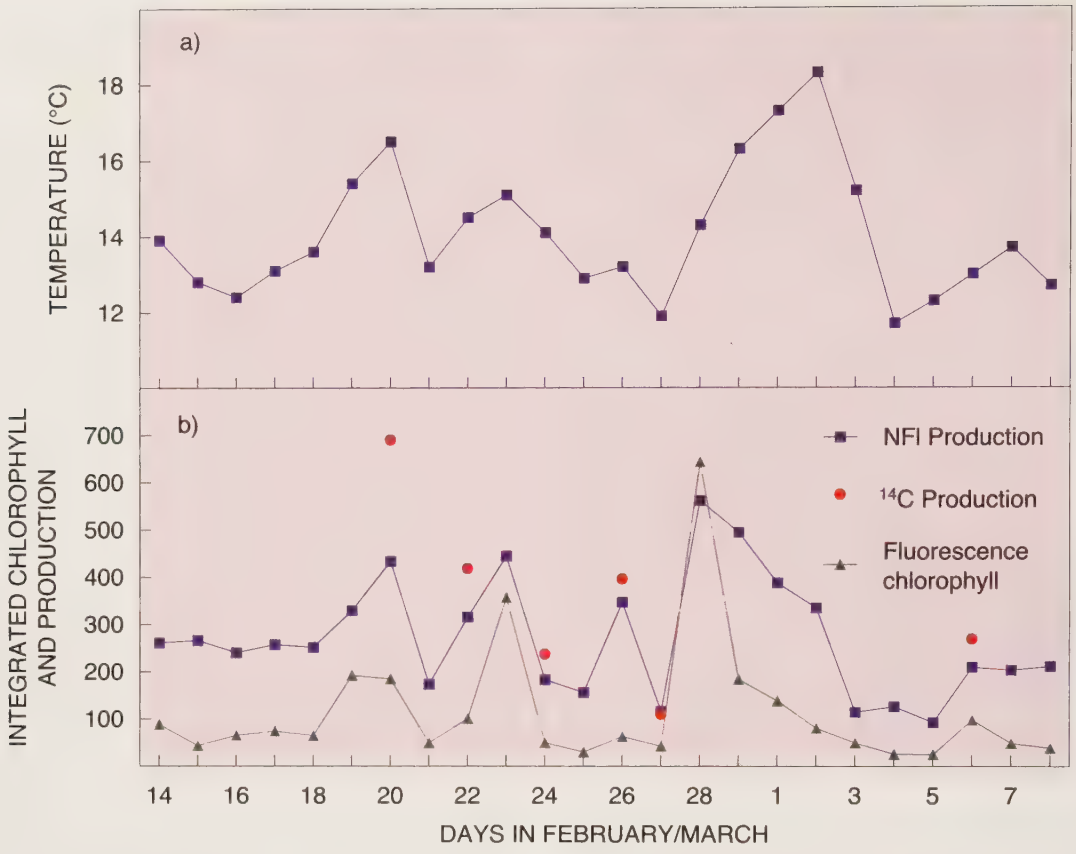

Fig. 49: Daily changes in a) sea surface temperature and (b) depth-integrated chlorophyll ($mg \cdot m^{-2}$) and primary productivity ($mgC \cdot m^{-2} \cdot h^{-1}$) measured by natural fluorescence and radiocarbon (^{14}C) uptake, at the monitoring station at Lambert's Bay from 13 February to 8 March 1996. Integrals are to 11 m

non-toxic and toxic phytoplankters and their grazers need to be conducted. This necessitates the incorporation of zooplankton research into phytoplankton dynamics studies focused on HABs.

Using natural fluorescence to measure primary production on the West Coast in late summer

Primary productivity, the fixation of carbon by phytoplankton in the sea, forms the basis of the food chain. With the development of new technology, it is now possible to measure *in situ* primary productivity quickly and easily by means of natural fluorescence, using an instrument called a Profiling Natural Fluorometer. Natural fluorescence, the solar-induced fluorescence of chlorophyll *a* within the water column, is an index of photosynthetic activity of the phytoplankton. There is good correspondence between measurements of primary productivity using the traditional ^{14}C method and those based on natural fluorescence, in a high biomass environment on the West Coast in late summer (Fig. 48).

An inshore monitoring station off Lambert's Bay was sampled daily over a 25-day period in February and March in 1996 (Fig. 49). The inshore region is very responsive to wind forcing, with hydrographic and biological changes within the water column occurring within hours of

wind events. Incursions of cold water during upwelling periods were low in chlorophyll but high in nutrients whereas warm water incursions were high in chlorophyll, with concentrations over 75 $mg \cdot m^{-3}$ on two occasions during red tides. Fluorescence-based photosynthetic activity in the water column mirrored the variability in chlorophyll, with peak activity coinciding with brief periods of high biomass during two red tides. On these occasions photosynthetic activities of more than 180 $mgC \cdot m^{-3} \cdot h^{-1}$ were recorded in near-surface waters.

These studies have shown that the West Coast, which is dominated by dinoflagellate populations in late summer and autumn, is a highly productive environment, rivalling that in diatom-dominated upwelling plumes off the Cape Peninsula. The relatively stable environment over the broad shelf on the West Coast in late summer and autumn, when there is a large biomass of larger-sized phytoplankton, provides an apparently ideal situation for larval development of pelagic fish.

Spring phytoplankton blooms and spawning success of sardine and anchovy

The western Agulhas Bank is the major spawning ground of anchovy and, to a lesser extent, of sardine. Monthly data collected as part of the intensive Sardine and Anchovy Recruitment Programme (SARP) cruises in 1993 and 1994 showed enhanced phytoplankton growth forming a spring bloom in September and / or October on the western Agulhas Bank (Fig. 50a). This bloom is a consequence of warming and stabilization of the water column after strong mixing by westerly winds in winter. Phytoplankton populations exposed to good light conditions in surface waters high in nutrients grow rapidly, forming moderate blooms, particularly over the inner shelf. During the SARP surveys, peak spawning of sardine, from August to October, and of anchovy, from October to December, both overlapped with the spring phytoplankton bloom.

The spring bloom, although modest, provides a stable food environment for copepods and for adult sardine. Sardine eat considerable quantities of phytoplankton and there appears to be a direct relationship between sardine egg production and

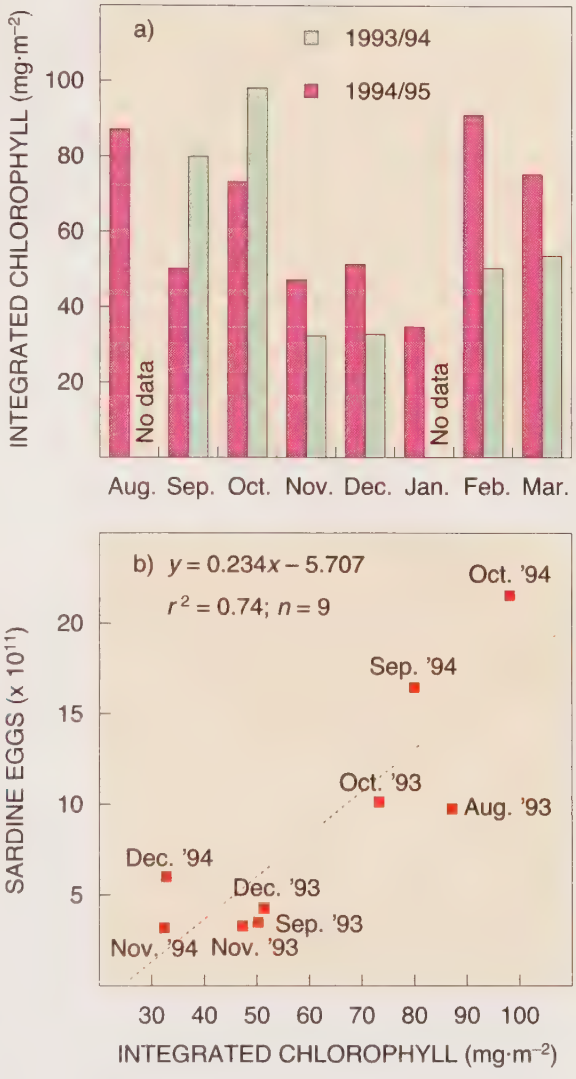

Fig. 50: (a) Monthly changes in integrated chlorophyll in the upper 30 m on the western Agulhas Bank during the 1993/94 and 1994/95 SARP cruises; (b) relationship between total number of sardine eggs and the integrated chlorophyll in the upper 30 m on the western Agulhas Bank from August to December 1993 and from September to December 1994

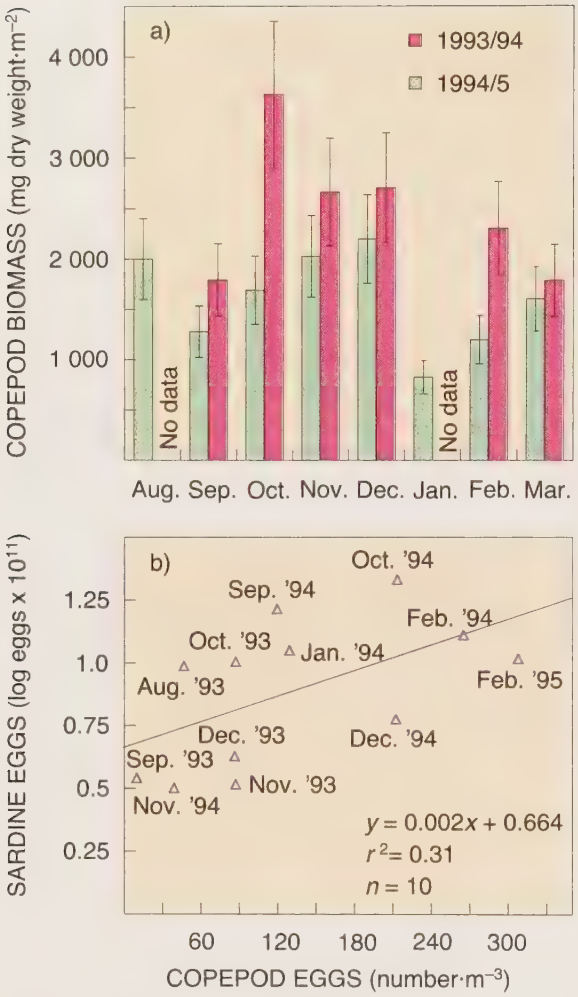

Fig. 51: (a) Monthly changes in copepod biomass on the western Agulhas Bank during the 1993/94 and 1994/95 SARP cruises; (b) relationship between total number of sardine eggs and copepod eggs during the SARP cruises

phytoplankton biomass (Fig. 50b). The moderate and relatively constant phytoplankton concentrations support a high biomass of copepods (Fig. 51a), the preferred food of anchovy. Copepod egg production is stimulated during the spring bloom, providing a food source for larval anchovy and sardine, which are particularly vulnerable to starvation (Fig. 51b).

The coincidence of phytoplankton blooms, rapid copepod growth and egg production and peak spawning of pelagic fish suggests closer linkages between these elements of the pelagic food chain than previously envisioned. With the latest remote sensing techniques using ocean colour, it may be possible to predict the spawning success of pelagic fish by monitoring the strength and duration of the spring bloom each year.

Is a historically disturbed macrobenthic community further disrupted by mariculture in Saldanha Bay?

Saldanha Bay has been impacted anthropogenically since 1905, when the first fish factories came into operation, releasing effluent that was not monitored until late 1980. In the 1970s, extensive dredging took place to construct a deep-water port and iron-ore jetty plus causeway, effectively dividing the bay into two segments, Small and Big Bay (Fig. 52). As a result of these activities and continuing industrial development, sedimentary organics have increased, oxygen levels have decreased and water circulation patterns have been altered in Small Bay.

Ecological impact has been most dramatically demonstrated in Small Bay by changes in the structure of benthic macrofaunal communities. Suspension feeders such as the sea-pen *Virgularia schultzei* and the cumacean *Iphinoe africana* previously dominated but are now secondary to deposit-feeding species like the polychaetes *Polydora* spp. and *Prionospio sexuculata*, the echiuroid *Ochaetostoma capense* and the prawn, *Upogebia capensis*. The shift to a new baseline community dominated by deposit-feeders demonstrates a reduction in particles suitable for suspension feeders and greater deposition of organic material onto bottom sediments. Clearly the major activities responsible for these environmental changes are reduced water circulation within the bay and increased organic inputs from effluents.

In 1984, raft-culturing of the Spanish mussel *Mytilus galloprovincialis* commenced in Small Bay and at present the annual yield is approximately

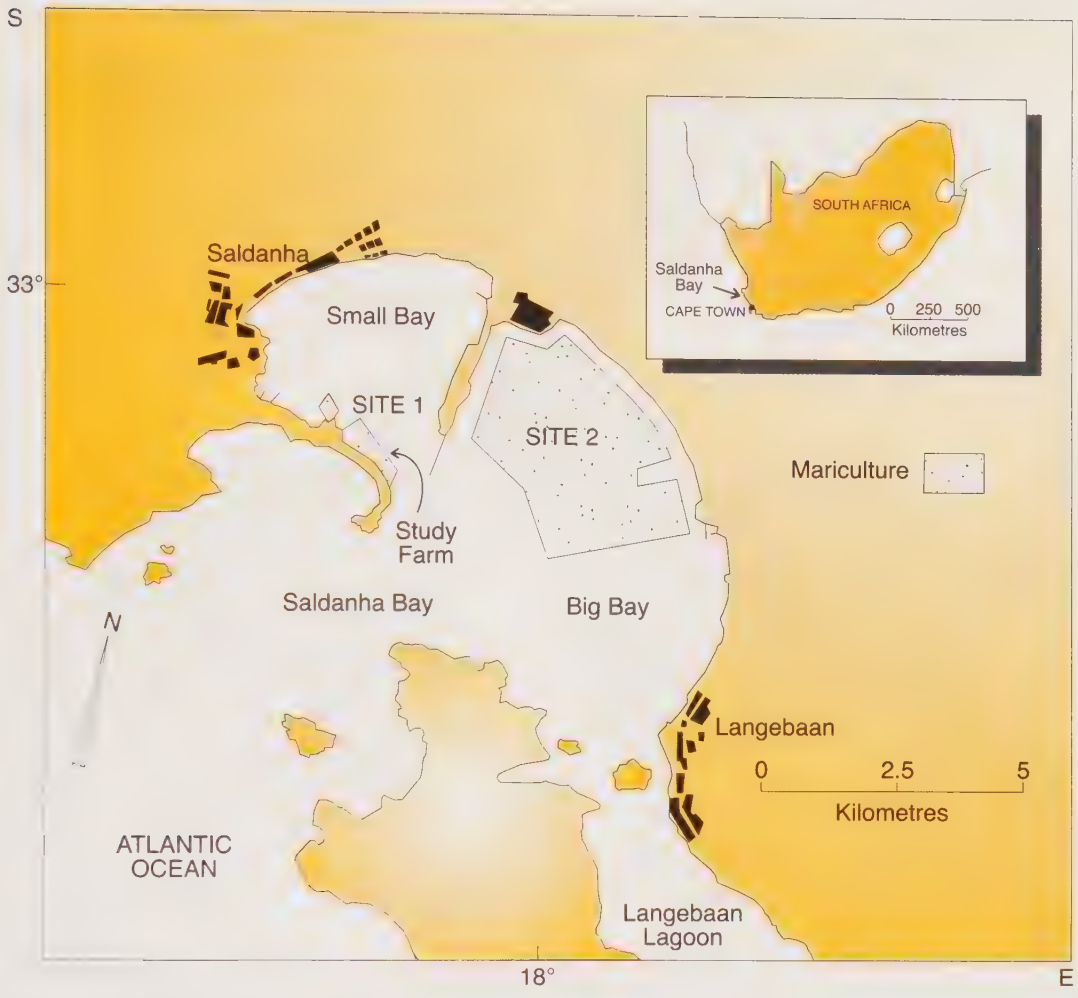

Fig. 52: Saldanha Bay, with the position of the present mussel farm in Small Bay (80 ha) and the new lease area (1000 ha) in Big Bay

2 000 tons wet mass from 70 rafts. The introduction of this fishery posed the question: would there be further environmental degradation? Using the trophic characteristics of macrofauna as an environmental indicator it can be asked: is a historically disturbed macrobenthic community further disrupted by mariculture in Saldanha Bay? A three-year survey indicated that macrofaunal communities below all rafts were dominated by deposit-feeders like the rest of Small Bay. The second dominant trophic position was replaced, however, by carnivores in the centre of the farm, while suspension feeders still hold second dominance under rafts on the periphery (Fig. 53). Typical scavenging carnivores were the gastropods *Nassarius speciosa* and *N. vintus*, the brachyuran *Hymenosoma orbiculare* and the polychaete *Eunoe nodulosa*.

Why is there a shift from suspension feeders to scavenging carnivores in the centre of the farm? Does this represent further environmental degradation? The sedimentation rate below the rafts is approximately three times that on the outside. The debris reaching the bottom includes not only particulates but also organic bulk from dislodged mussels and other marine organisms

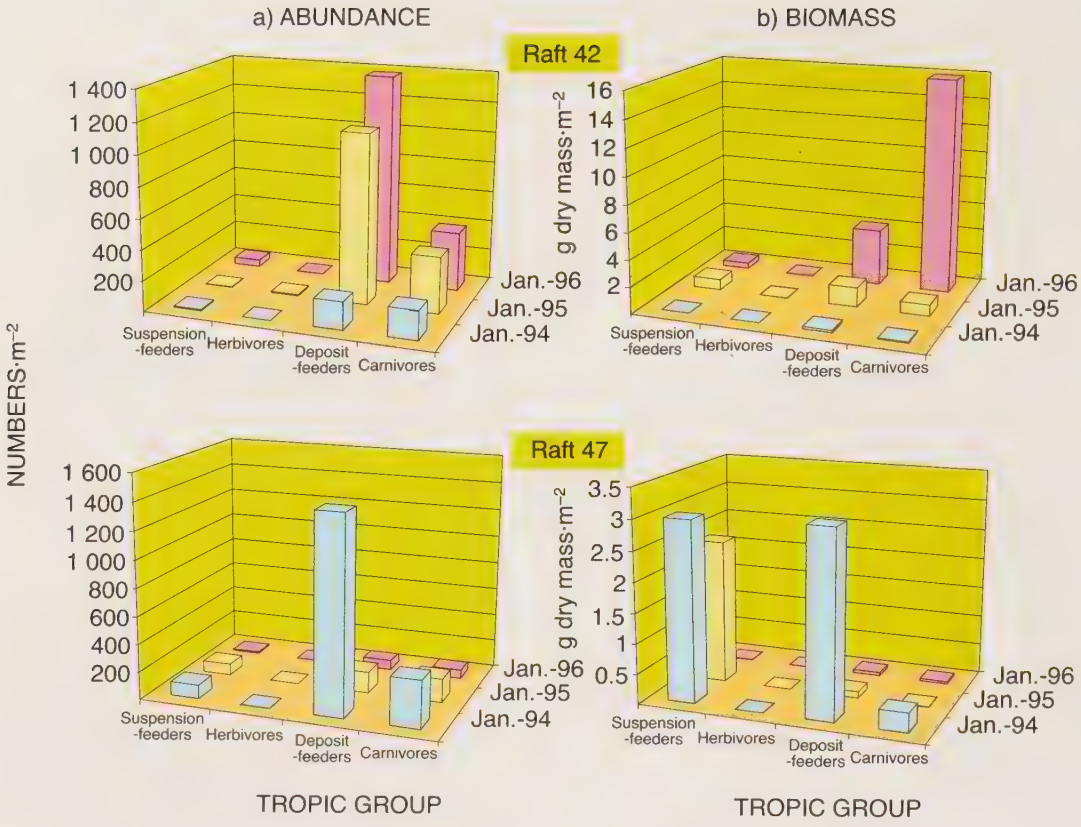

Fig. 53: (a) Abundance (number·m⁻²) and biomass (g dry mass·m⁻²) of suspension feeders, herbivores, deposit-feeders and carnivores under a raft in the centre of the farm (42) and one on the periphery (47)

that colonize the rafts opportunistically. The bottom sediments become smothered in a thick layer of debris, which precludes the suspension mode of feeding but encourages scavengers. This is most prevalent in the centre of the farm where the drag force of the rafts is greatest, impeding water circulation and leading to less debris dispersion and greater concentration of deposits than under peripheral rafts.

The change in feeding mode is indicative of advanced environmental degradation that exceeds that observed in the rest of Small Bay. This observation is supported by physiochemical data: greater sediment oxygen demands and net nutrient fluxes across the water-sediment interface. While highly localized, such degradation implodes on the health of the bay ecosystem, a bay that has for nearly 100 years faced enormous anthropogenic disturbance. Present research is focused on exploring this ecosystem in an attempt to holistically quantify, in a trophic-level model, the environmental impact of mariculture within an anthropogenically-altered embayment.

The influence of meso-scale circulation patterns in the Benguela Current on hake spawning sites

In October 1998 the *R.V. Dr Fridtjof Nansen* undertook a cruise off Namibia as part of the BENEFIT programme, to investigate further the relation between the oceanographic environment and hake spawning. Previous work had suggested that hake eggs are spawned at depth, and, as

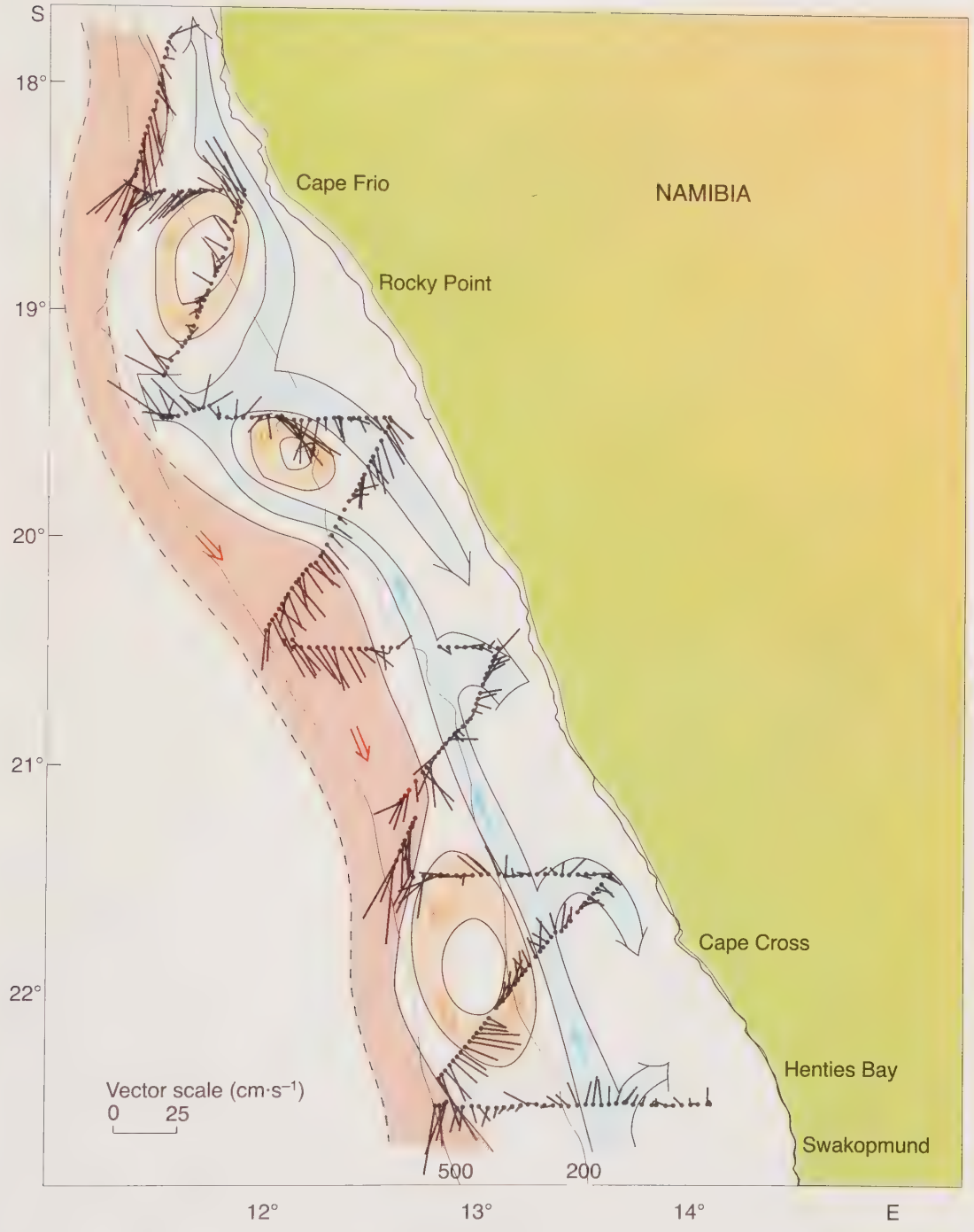

Fig. 54: Spatial average of 35–50 m currents and schematic interpretation

they are neutrally buoyant, they rise up to the surface inshore as part of the upwelling process. The 1998 study examined the horizontal distribution of hake spawning and the environment with sufficient resolution to come up with an additional hypothesis: that spawning centres

coincide with (subsurface) mesoscale gyres. The evidence for this from the October 1998 cruise is summarized below.

Firstly, apart from some onshore winds opposite Henties Bay and Swakopmund, winds were uniformly longshore from the south. This led to upwelling and the dominant longshore orientation of surface (10 m) isotherms and isohalines, although both salinity and temperature increased northwards. Secondly, average currents at the surface (1 m deep), measured by Argos Drifters over two years, earlier in the decade, showed longshore and offshore flow, consistent with these distributions.

On the other hand, currents 35–50 m deep, below the upper mixed layer, measured by means of an Acoustic Doppler Current Profiler (ADCP), showed a completely different pattern. Current vectors averaged every two miles (with a proposed schematic circulation pattern) are shown in Fig. 54. Eddies are suggested north of 19 and 20°S, and at 22°S. There was a thin band of northward flow just inshore of the 200 m isobath in the central region. Southward flow was dominant on the outer shelf and shelf-edge, as well as on the inner shelf (apart from the region off Cape Frio). Some of the structures in the thermocline-level currents are shown in the midwater hydrology (presented as the depth of

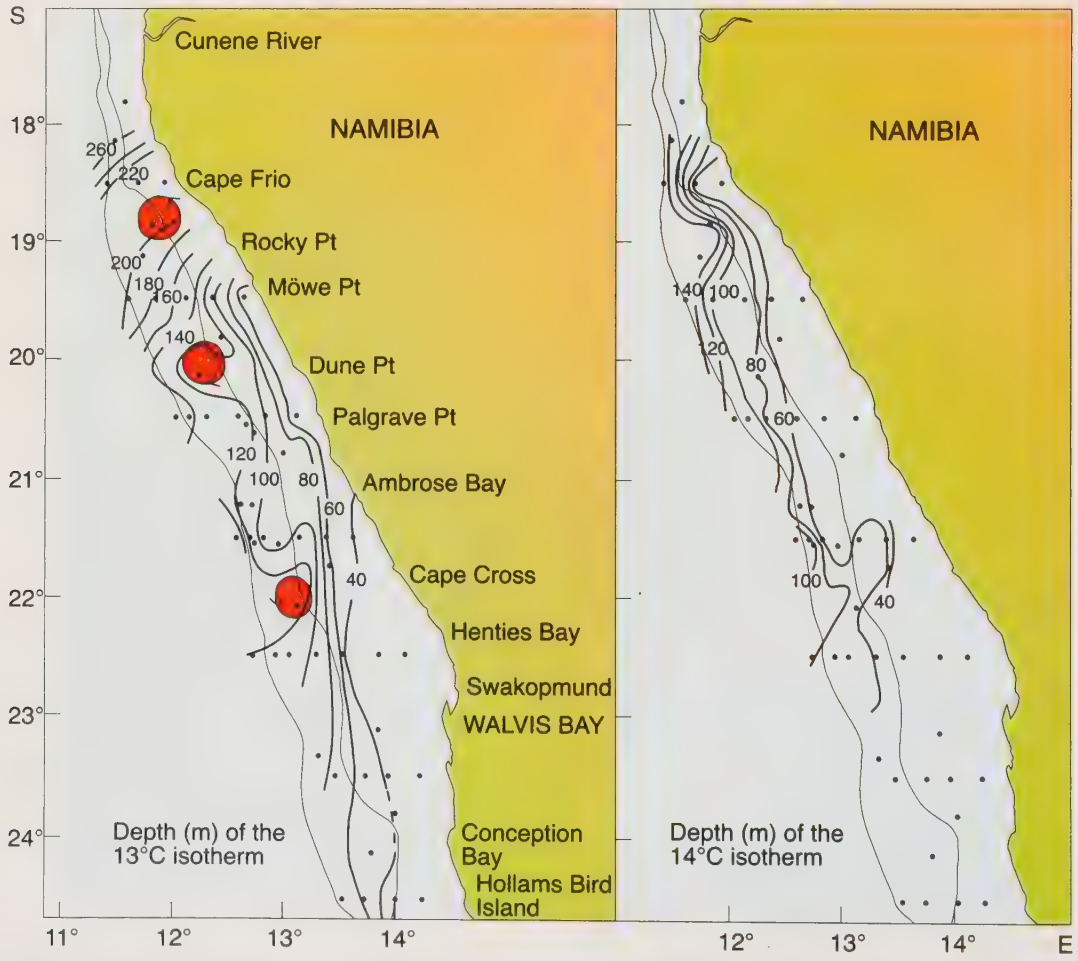

Fig. 55: Some of the structures in the 35–50 m depth currents are shown in the mid-water hydrology (presented as the depth of the 13 and 14 degree C isotherms)

the 13 and 14°C isotherms in Fig. 55), with very good agreement for the northern and southern structures but less agreement with regard to the position of the central structure at 20°S .

Fig. 56: Concentration of hake eggs during the October 1998 cruise

Thirdly, the location of these eddy structures appears to have influenced the horizontal position of hake eggs (as shown in Fig. 56) and larvae. The concentration of eggs at 20°S agrees better with the position of the eddy shown in the subsurface hydrology in Fig. 55, but the other two egg concentrations are singularly located at the eddy sites. This cruise also provided information indicating that, where there is very low oxygen in bottom waters, hake rise in the water column to spawn.

An Atlantic Meriodinal Transect cruise was undertaken by British scientists during May/June 1998 from Cape Town to the UK on board the RRS *James Clark Ross*. One of the key objectives of the cruise was to perform *in situ* optical and pigment ground-truthing measurements for the calibration and validation of the SeaWiFS satellite data that are now providing ocean colour images of the global ocean. A local scientist participated in the cruise to conduct the pigment measurements using an advanced high pressure liquid chromatography (HPLC) technique.

Optical and pigment data were sent to NASA in the USA at regular intervals during the cruise. These data were used to modify the algorithm that generates the chlorophyll ocean colour images from the water-leaving radiances detected by the SeaWiFS sensors. Chlorophyll concentrations estimated from the SeaWiFS and *in situ* optical data using the modified algorithm were compared with those measured by the accurate HPLC method. Figure 57a shows that chlorophyll estimated from *in situ* optical data compare well with HPLC measurements, for the selected data from the Benguela ecosystem. Chlorophyll estimated from SeaWiFS data compared poorly with HPLC levels. The reason for this is that atmospheric correction estimates were inaccurate and further research is required to produce accurate atmospheric correction algorithms.

Pigment data are also useful for determining the chemotaxonomic composition of phytoplankton communities. Chlorophyll *a* is a measure of phytoplankton biomass and accessory pigments such as fucoxanthin and peridinin are biomarkers of the larger diatoms and dinoflagellates, respectively. Hexanoyloxyfucoxanthin, butanoyloxyfucoxanthin, alloxanthin and chlorophyll *b* indicate the presence of various nanoflagellates (2–10 microns), whereas zeaxanthin is a signature for the picoplanktonic prokaryotes (0.5–2 microns). The surface distribution of chlorophyll along the cruise track in the Benguela revealed considerable variation in concentration, with patches of very high chlorophyll in the southern sector dominated by dinoflagellates, as indicated by the high peridinin levels (Fig. 57b). Diatoms (fucoxanthin) were prominent throughout the Benguela transect (Fig. 57c) and nanoflagellates were also significant in the south. Prokaryotes (zeaxanthin) were present in the Benguela, but in very low concentrations (Fig. 57c). Overall, the pigment data revealed a mixed community of diatoms, dinoflagellates and nanoflagellates in the southern Benguela between 34 and 26°S in May/June, while the phytoplankton in the northern Benguela was dominated by diatoms. As phytoplankton is at the base of the food chain, these variations in community composition have important implications for the structure of zooplankton and fish populations.

Two of South Africa's abundant seabirds are the Cape gannet *Morus capensis* and Cape cormorant *Phalacrocorax capensis*. Both are endemic to southern Africa, breeding only along the coasts of South Africa and Namibia, where they feed mostly on shoals of pelagic fish, notably sardine and anchovy. Their numbers are related to the abundance of these prey species.

Trends in populations of Cape gannets are gauged from aerial photographs of colonies taken during the breeding season. They breed at just six islands, three off Namibia and three off

Fig. 57: (a) Chlorophyll concentrations estimated from HPLC, in situ *optics and SeaWiFS data and (b) and (c) surface pigment distribution patterns in the Benguela ecosystem. Pigment identities are Chla-chlorophyll* a*; Per-peridinin; Fuc-fucoxanthin; H-hexanoyloxyfucoxanthin; B-butanoyloxyfucoxanthin; A-alloxanthin; Cb-chlorophyll* b*; zea-zeaxanthin*

South Africa. Between 1956 and 1996 numbers decreased by 31%, and between 1978 and 1996 by 15%. Cape gannets have a generation time of 13–14 years (mean age at first breeding is four years, and adult survivorship about 93%). Hence, both decreases are equivalent to >50% in five generations, and therefore in terms of criteria of The World Conservation Union (IUCN) the species warrants classification as Vulnerable. This situation is attributable to very large

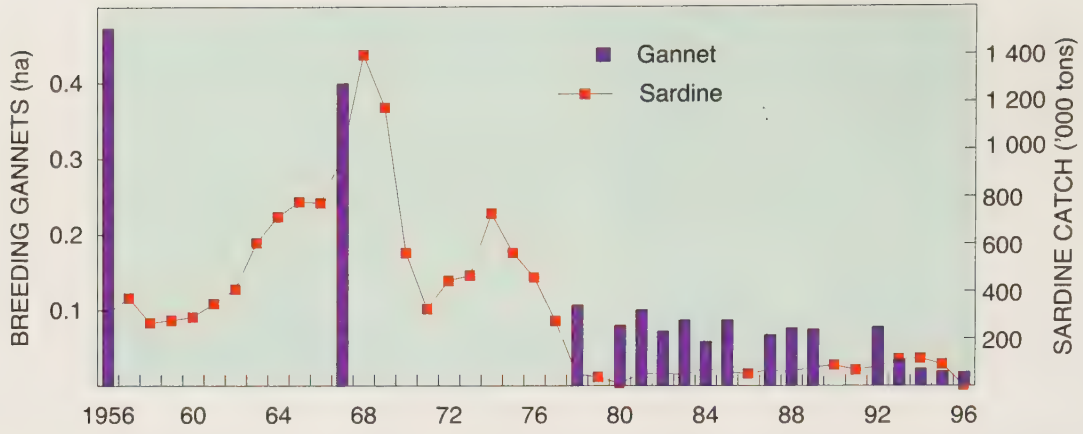

Fig. 58: Breeding area of Cape gannets at Possession Island compared with Namibia's sardine catch, 1956–1996

decreases at the three Namibian colonies. At Mercury Island, area occupied by breeders reduced from 0.25 ha in 1956 to 0.05 in 1996; at Ichaboe Island from 5.52 to 0.56 ha; and at Possession Island from 0.47 to 0.02 ha. Fortunately, numbers at South African colonies increased in the same period: at Bird Island in Lambert's Bay from 0.18 to 0.34 ha; at Malgas Island from 0.88 to 2.10 ha; and at Bird Island in Algoa Bay from 0.70 to 2.40 ha. However, these increases were insufficient to offset the losses in Namibia.

The decrease at Namibian colonies followed the collapse of the sardine population there, as is illustrated by Figure 58, showing the Namibian sardine catch and the abundance of gannets at Possession Island. Although sardine also decreased off South Africa in the 1960s, anchovy subsequently provided sufficient alternative forage for the gannets, as may be seen from the trend at Lambert's Bay (Fig. 59). Clearly, this was not the case off Namibia. Ringing records indicate that, after the collapse of the Namibian sardine, some birds banded as chicks in Namibia relocated to South African colonies.

The reason for the more successful replacement of sardine by anchovy off South Africa than off

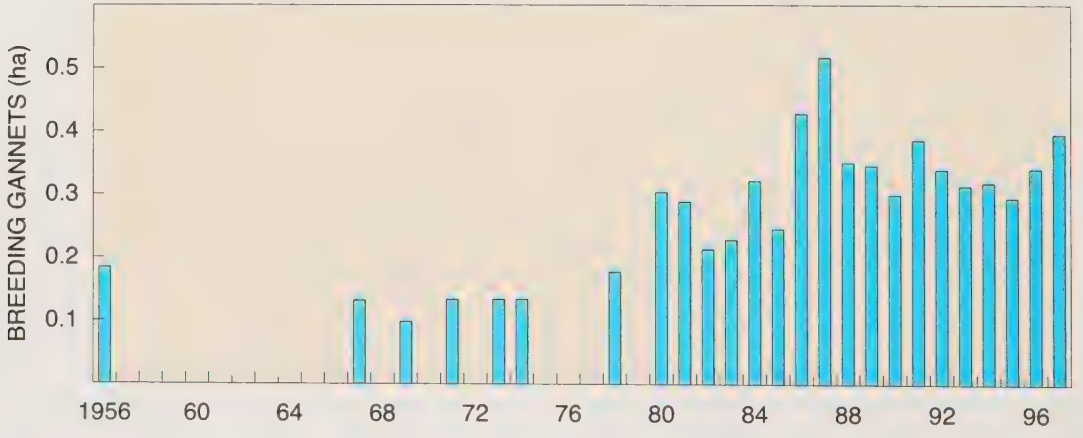

Fig. 59: Breeding area of Cape gannets at Bird Island, Lambert's Bay, 1956–1997

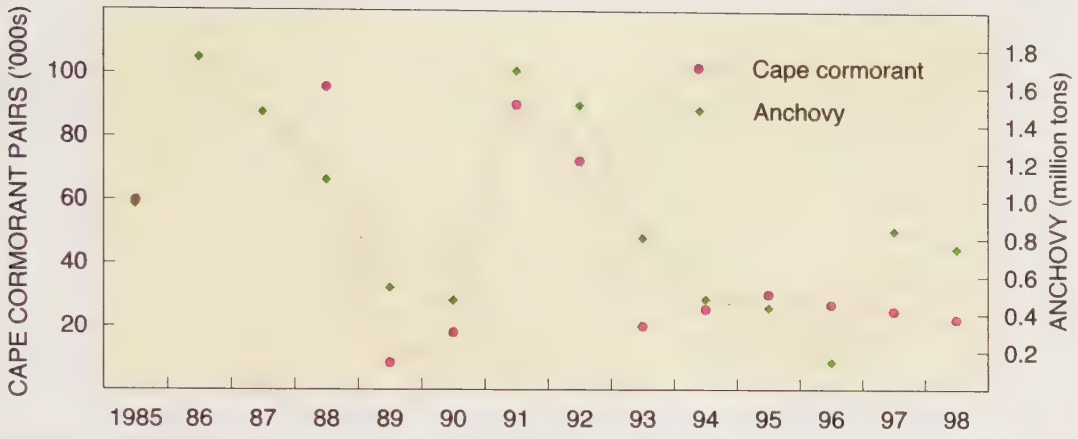

Fig. 60: Numbers of Cape cormorants breeding off western South Africa compared with survey estimates of the biomass of anchovy off South Africa, 1985–1998 (no data for Cape cormant in 1986 and 1987

Namibia is of considerable interest. One possibility is the disparate fishing policies that were pursued in the two countries. Once sardine had collapsed in South Africa, anchovy became an attractive alternative resource with which to perpetuate the fishery, and attempts were made to manage it sustainably. When sardine collapsed off Namibia, the South African experience prompted belief that anchovy was a competitor of sardine and that this competition would be minimized by subjecting the anchovy to heavy fishing pressure.

More recently, sardine has increased and anchovy decreased off South Africa. The gannets have responded to this change by reverting to sardine as their main food item.

Cape cormorants breed at 69 localities, mainly along the western coast of southern Africa. Less than 2% of the population breeds east of Cape Agulhas. The overall population was about 247 000 pairs in 1977–81, but it fell to just 72 000 pairs in 1996. Off South Africa, the breeding population is closely related to the biomass of anchovy, as shown in Figure 60. Therefore, Cape cormorants appear less able than Cape gannets to switch their diet from anchovy to sardine. The long-term fluctuations in abundance of anchovy may be part of a natural cycle, so at this stage Cape cormorants are not classified as Vulnerable. However, anchovy is at present decreasing off southern Africa, and the situation warrants monitoring.

Bacular and testicular growth in the Cape fur seal

The dynamics of the Cape fur seal *Arctocephalus pusillus pusillus* population are managed using a seal population model. Although most parameters required by the model are known, values for some key parameters must be estimated. These include the age at which bulls become socially mature and are able to defend a territory successfully. The growth and allometry of the baculum (penis bone) and testis were investigated as possible indices of the age at social maturity.

Relative growth rates between years revealed two spurts in growth. The first pubertal growth spurt occurred between two and three years and was followed by the social maturity spurt at between nine and ten years (Fig. 61). There was little growth thereafter.

The pubertal growth spurt is indicated by bacular length increases of 28% and body length increases of 14%. This interpretation is strengthened by the observation that most testicular growth occurs by three years of age, when most males first exhibit spermatogenesis. Growth in testicular length

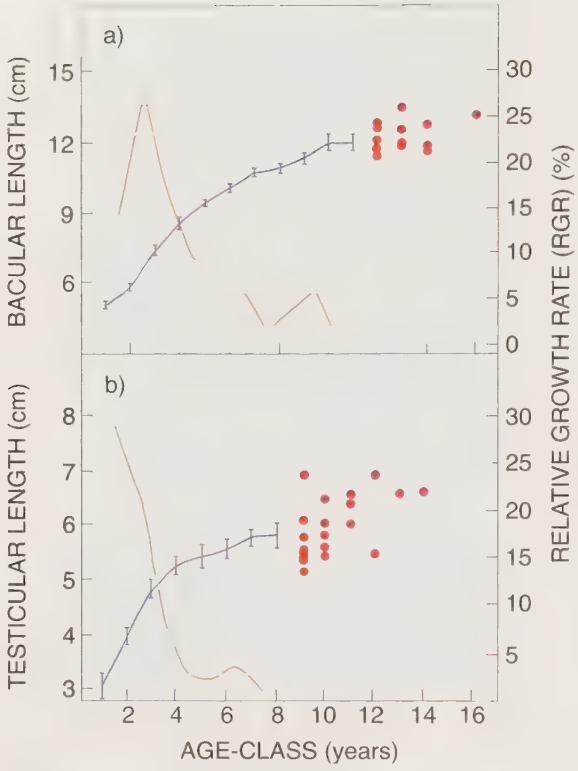

Fig. 61: (a) Growth in bacular length and (b) testicular length. Means and 95% confidence intervals on means are shown for age-classes with n > 10; raw data are shown for other age-classes. Relative growth rates (RGRs) are plotted as dashed curves. Transitions between 2 and 3, and between 9 and 10 years of age, are represented by shaded rectangles. Testicular data were from March and April only

was rapid from 1–3 years of age, then slowed, reaching a maximum at approximately 6.0–6.5 cm. Cape fur seals exhibit spermatogenesis and acquire large bacula years before they can compete for territories. Early spurts in body growth may be adaptively timed to occur when resources are abundant or mortality rates are low, but these factors seem less applicable to rapid development of bacula and testes. In the northern fur seal, young males mate with females late in the breeding season, and Cape fur seal males may mate before the pupping season. Physiological readiness for mating in young male otariids may be a natural consequence of strong selective pressure on males to find alternative (and earlier) modes of achieving reproduction, because only a minority of males will survive to acquire territories and fertilize mature females.

The second, weaker spurt, that occurs in body and bacular growth at 9 –10 years of age, indicates that male Cape fur seals become socially mature and territorial during the breeding season. Rapid body growth then seems clearly adaptive in terms of the advantage large size offers in establishing and holding territories. The spurt in bacular growth suggests that increased bacular size becomes adaptively significant around the same time, though reasons for this are unclear.

Growth-related allometry of the baculum in relation to body size in the Cape fur seal is strongly positive. Patterns of early growth and allometry of the baculum and testes are interpreted as adaptations for mating opportunities, years before territoriality is possible. The pattern of rapid pubertal growth in bacular size in the Cape fur seal and other pinnipeds suggests that there are appreciable adaptive advantages to large bacular size in young males.

The objectives of the by-catch programme funded by SANCOR (South African Network for Coastal and Oceanic Resources) are to quantify the by-catch (retained, non-target catch) and discards in both the inshore and offshore trawl fisheries. They allow for improved stock assessment, and hence management of the resource, as well as for the identification of possible markets for species currently discarded.

On-board observers are the primary means of collecting data on vessel type, trawl position and duration, as well as mass and length frequency data for all discarded species. Observers continued the collection of data during 1998, bringing the total number of trawls observed to 965. Data collection on the West Coast is now nearly complete for the wetfish vessels. The collection of

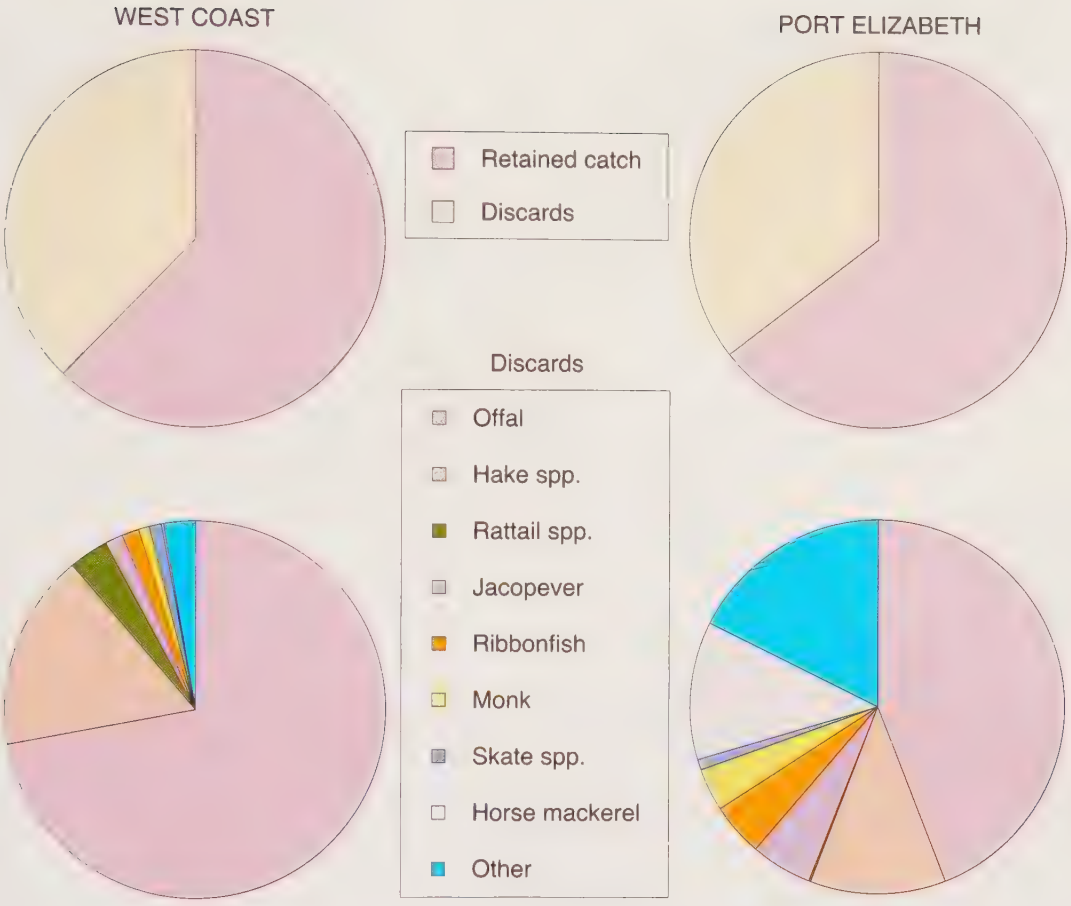

Fig. 62: Catch composition % of trawls observed on the West Coast (n=402) *and Port Elizabeth* (n=65)

data from freezer trawlers will continue during 1999. Because of the diversity of vessel types operating from Mossel Bay, a large dataset is required from there and observers will hopefully continue collecting data throughout 1999. Preliminary results from trawls on the West Coast show that 62.2% of the total catch was retained. Discarded offal contributed 27.4% by mass to the total catch, whereas discarded hake accounted for 6.3% by mass (Fig. 62). Of the hake discards on the West Coast, approximately 50% were < 30 cm (Fig. 63). These fish are discarded because they are too small to fillet. Large fish are probably discarded only as a result of net damage. Preliminary data from Port Elizabeth trawls showed that 64.5 of the catch was retained. Discarded offal and hake accounted for 15.7% and 4.2% of the total catch respectively.

The collection of biological data is an important aspect of the study, and data on the biology of the Cape dory *Zeus capensis*, jacopever *Helicolenus dactylopterus*, purple rattail *Malacocephalus laevis*, rough rattail *Coelorinchus simorhynchus* and the monkfish *Lophius vomerinus* are currently being analysed. A study on the biology of the Cape gurnard *Chelidonichthys capensis* was completed at the beginning of 1998 and a similar study into the biology of the ribbonfish *Lepidopus caudatus* will be initiated in 1999.

Investigations into chondrichthyan fisheries (both directed and by-catch) continued during 1998.

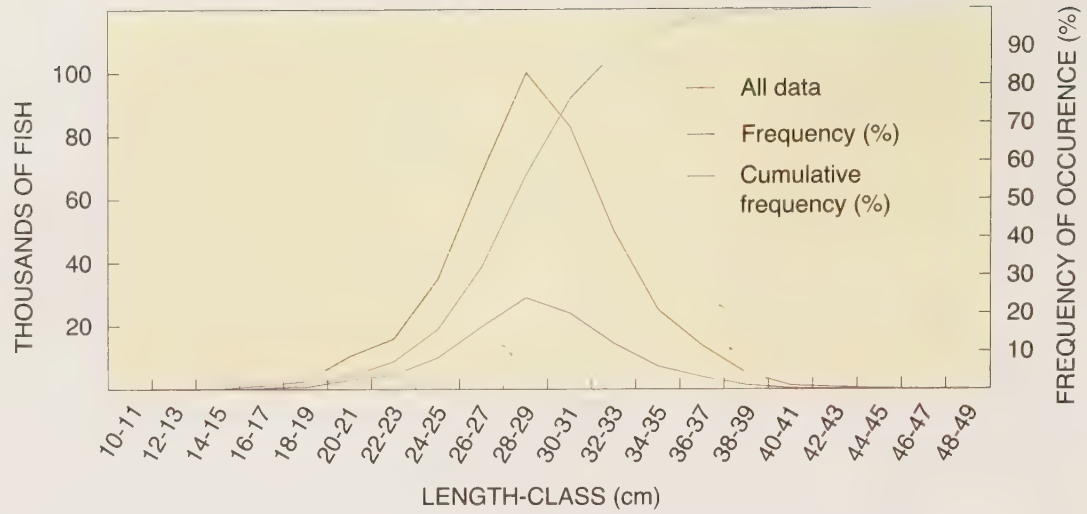

Fig. 63: Length – frequency plot of hake discards observed on the West Coast of South Africa

Of all the fisheries catching elasmobranchs, the demersal fleet had the largest discard rate. There has been increased targeting of elasmobranchs in South Africa because of overseas demand, and management strategies to prevent overcapitalization in the fishery are under review. Initial modelling of the soupfin shark *Galeorhinus galeus* is underway.

An investigation into the socio-economics of by-catch and the attitudes of large companies, small producers, skippers and trawlers regarding by-catch and discarding was also carried out. The results, along with those from a preliminary investigation into the economics of by-catch, were presented internationally in September 1998. In 1998, the socio-economic group initiated two new projects: an investigation into the potential of reducing offal into fishmeal and the utilization of hake "tongues" and "cheeks" as a potential food source.

Research in the Southern Ocean

Research in the Southern Ocean is undertaken in support of South Africa's obligations to the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). The research is divided into three major components, which provide input into the CCAMLR Ecosystem Monitoring Programme (CEMP) and underpin the management of exploited stocks.

The first component focuses on the resource potential and management of Antarctic krill *Euphausia superba*. In cooperation with scientists at the University of Cape Town, in-house officials remain at the forefront of developing models of krill spatial distribution as a basis for managing the Antarctic krill fishery and in the study of krill predator-prey relationships. Acoustic information collected during various research cruises to the Southern Ocean is used to describe the distribution of krill abundance which is then employed in the modelling of krill potential yield in various areas. A significant development in this regard has been the development of a one-way model to describe possible functional relationships between harvesting activities and the population dynamics of selected krill predators. Work on factors inducing krill-aggregation formation, maintenance and dispersal continues.

The monitoring of seabirds at Marion Island constitutes the second Southern Ocean research component. In 1998, MCM collaborated with

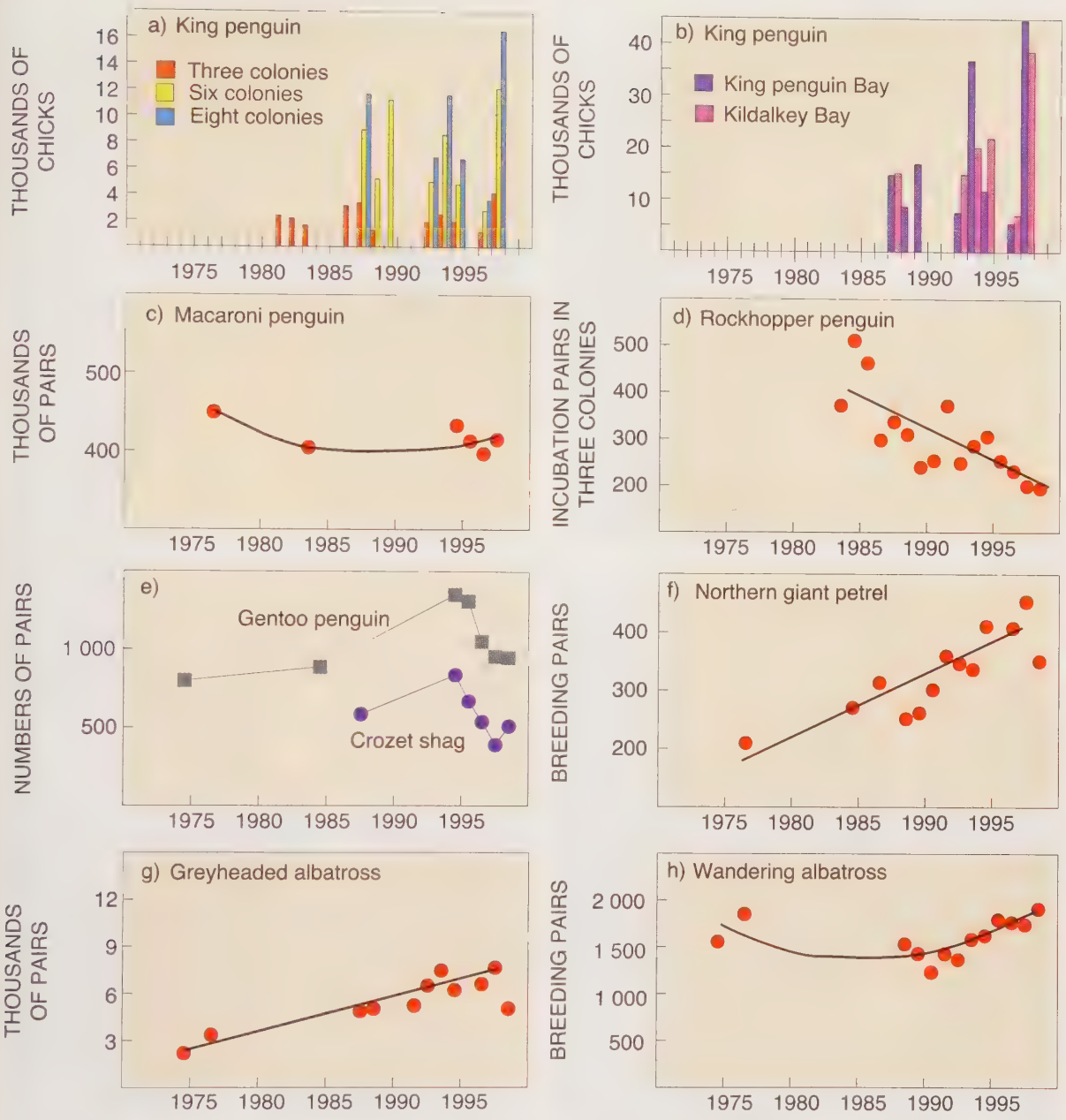

Fig. 64: Trends in the populations of some seabirds at Marion Island. Peaks in estimates of numbers of chicks of king penguins after the winter fast have increased, both for various combinations of the eight smaller colonies (a) and at the two large colonies (b), suggesting that the overall breeding population is increasing. The population of macaroni penguins appears stable (c), but rockhopper penguins are decreasing at a rate in excess of 4% p.a. (d). Both gentoo penguins and Crozet shags have recently decreased (e). Populations of northern giant petrel (f), greyheaded albatross (g) and wandering albatros (h) have recently increased. Species with a large foraging range have increased, whilst inshore feeders have recently decreased and the macaroni penguin, which has an intermediate foraging range, has remained stabele

Fig. 65: *(a) Wandering albatross* Diomedea exulans, *(b) King Penguin* Aptenodytes patagonicus, *(c) Macaroni Penguin* Eudyptes chrysolophus, *(d) Crozet shag* Phalacrocorax melanogenis

the Avian Demography Unit and the Percy Fitzpatrick Institute of African Ornithology (both at the University of Cape Town) and the Department of Zoology and Entomology at Rhodes University to collate past estimates of the population sizes of seabirds that nest above ground at Marion Island and interpret trends. Trends may be grouped into three categories – species that have increased since 1980, those that have remained stable and those that have decreased during the 1990s. Examples of these trends are illustrated in Fig. 64 and it is interesting to note that those species which have demonstrated increases (wandering albatross *Diomedea exulans* (Fig. 65a), greyheaded albatross *Diomedea chrysostoma*, northern giant petrel *Macronectes halli* and king penguin *Aptenodytes patagonicus* (Fig. 65b)) are all able to forage over relatively large distances.The macaroni penguin *Eudyptes chrysolophus* (Fig. 65c), whose population has been stable, forages over intermediate distances, whereas the three species that exhibited population decreases in the 1990s (rockhopper penguin *Eudyptes chrysocome*, gentoo penguin *Pygoscelis papua* and Crozet shag *Phalacrocorax melanogenis* (Fig. 65d)) all feed nearshore.

These trends may be related to a southward movement of the Subantarctic Front upstream of Marion Island. The region's oceanography is such that southward movement of the Front would decrease production close to the Island and so reduce food for inshore feeders. Farther offshore, the situation would be reversed, with zooplankton being advected towards the Island and thereby enhancing the food supply of offshore feeders. Evidence for a southward migration of the Front comes from the growing proportion of tropical and subtropical species compared to Antarctic species in the zooplankton collected around Marion Island since 1980. It is speculated that southward migration of the

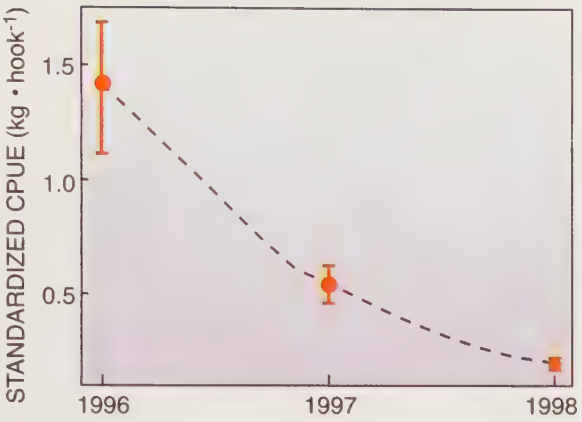

Fig. 66: Standard annual catch rate (cpue) *of toothfish in the South African fishery of the Prince Edward Islands*

Front is likely to be driven by change in the global climate.

The third area of Southern Ocean research relates to the management of the longline fishery for Patagonian toothfish *Dissostichus eleginoides*, particularly in the vicinity of the Prince Edward Islands. Data collected from an integrated monitoring scheme, using scientific observers and satellite-tracking, are submitted to CCAMLR and used in setting catch limits for the region as a whole. However, both the national and the CCAMLR Toothfish fishery have suffered from high levels of illegal, unregulated and unreported fishing. The impact of these activities has been so marked that *cpue* for toothfish in the Prince Edward Island EEZ has dropped dramatically over the past three years (Fig. 66). Coupled with a downward trend in the mean size of fish caught, the future potential of this fishery appears bleak. Serious consideration is therefore being given to more stringent enforcement measures and the undertaking of a fisheries-independent monitoring survey of toothfish stocks around the Prince Edward Islands in the near future.

Advances in hydroacoustic research

One of the primary challenges associated with *in-situ* target strength (TS) estimates is ensuring that multiple echoes originating from closely spaced fish targets in the same pulse volume are rejected and excluded from analysis. Failure to achieve this may lead to imprecise TS estimates and a consequent increase in the uncertainty attached to the biomass assessment. Although practical steps may be taken to reduce the acceptance of spurious echoes (e.g. conducting TS experiments at night when fish are more sparsely aggregated and/or choosing areas where fish densities are low), additional screening of data is generally necessary to improve the data quality. This screening is implemented by means of "single target detector" algorithms that automatically reject spurious echoes on the basis of user-selected parameters.

An experimental enhanced single target detector (ESTD) system has been developed which overcomes limitations on target screening imposed by current scientific split-beam echo-sounders. The ESTD system, which runs in parallel with the survey sounder, provides access to each of the four receiver channels and allows the use of additional algorithms to provide increased rejection efficiency and improved selectivity of potential targets in regions of high density (Fig. 67). The expanded target dataset output by the ESTD system is directly comparable with target strength data obtained from scientific echo-sounders employed on local fisheries research vessels. This provides a means of both validating and improving the precision of current *in situ* TS estimates.

Additional collaborative research to investigate the possibility of using multiple frequencies from co-located transducers to improve screening efficiency has been carried out under controlled conditions. The initial investigation entailed the use of three frequencies to isolate targets from an

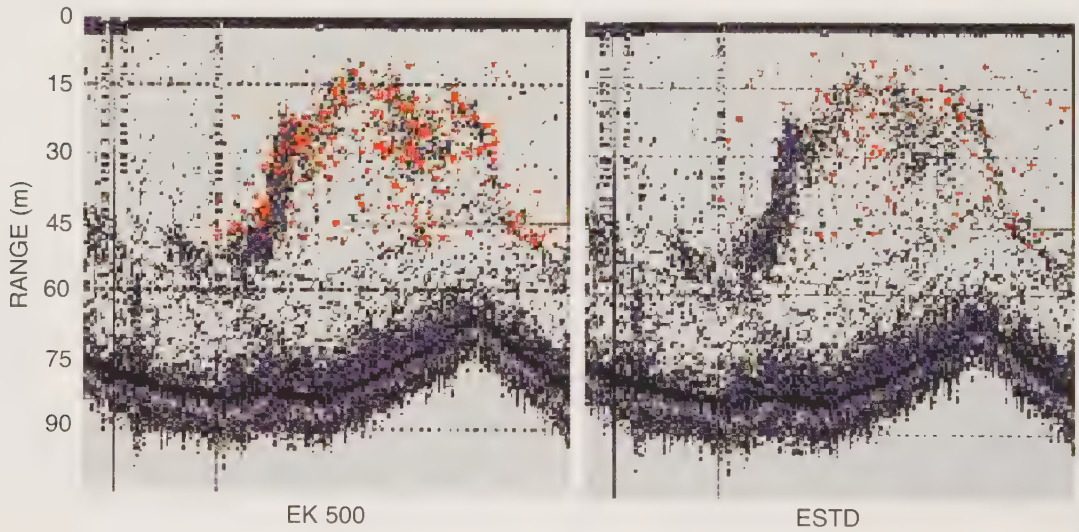

Fig.67: Duplicate echograms (300 pings) showing single target detections (red dots) for the EK500 scientific echo- sounder and the ESTD system after screening an identical set of potential single target echoes. The increased electivity of the ESTD system in regions of high scatterer, density where the potential for accepting spurious targets is high, is clearly evident.

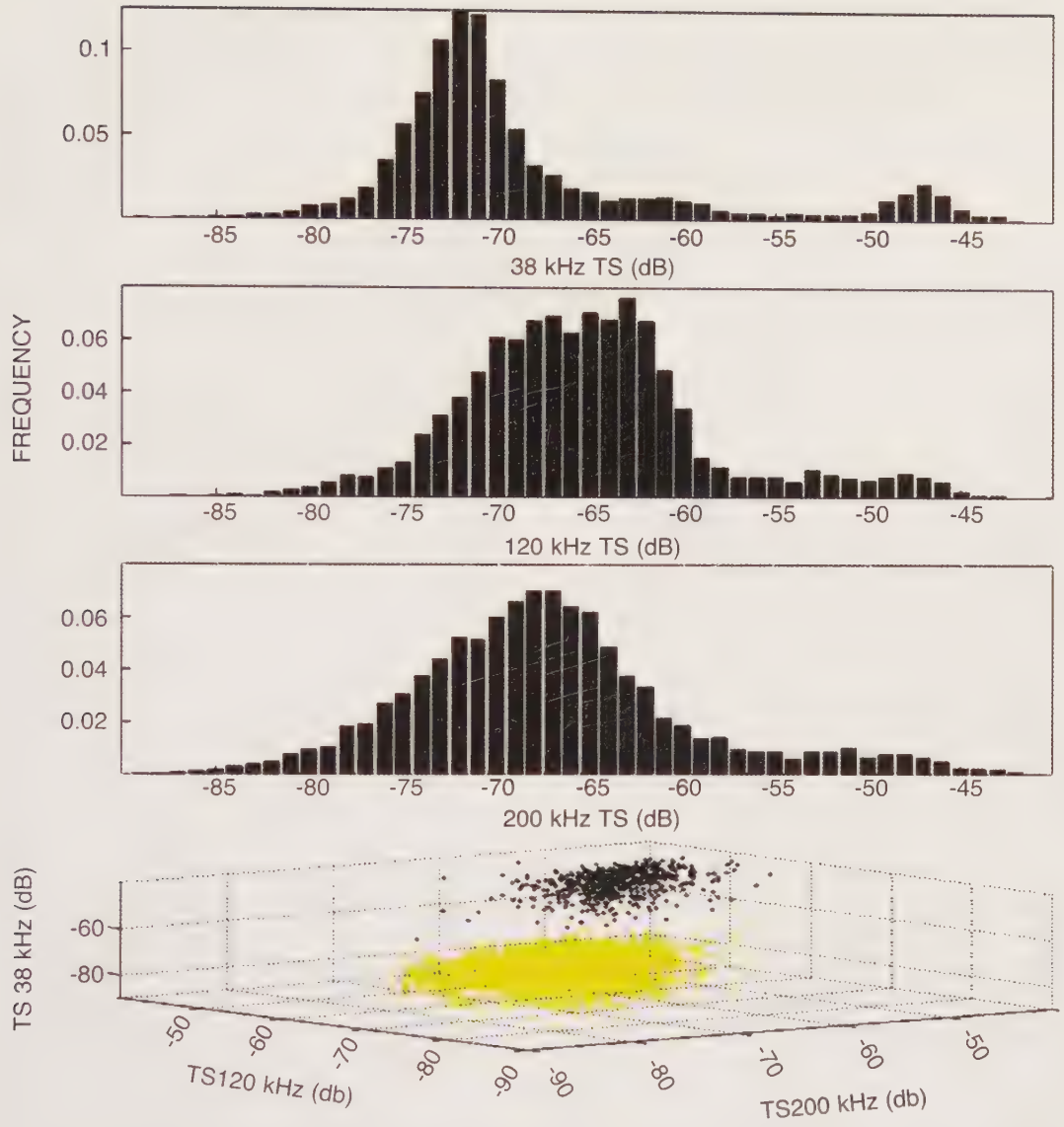

Fig. 68: In situ *target strength of Antarctic scatterers at 38, 120 and 200 kHz. The 38kHz histogram (top) contains three modes: –85#* mode 1 < *–65; –65#* mode 2 < *–55; and –55 #* mode 3 < *–40 dB. Modes 1 (black dots) and mode 3 (yellow dots) are clearly distinguishable by the differences in target strength between frequencies (bottom)*

ensemble of spherical targets in a test tank. The results from this study showed that the method has definite merit and may well offer performance in excess of that obtained with the single-frequency ESTD system described above. Comparative performance tests have been completed and the results are currently being analysed. A further important advantage that may be derived from using multiple frequencies is the potential for utilizing the differences in acoustic backscatter from different marine species as an aid to species identification (Fig. 68).

M&CM RESEARCHERS IN THE INTERNATIONAL ARENA

The organisation remains committed to fostering international partnerships, since this serves to fulfil national obligations to various international agreements and tremendously benefits the research undertaken by its staff.

In fulfilling current international obligations, M&CM is responsible for representing the South African Government at numerous international commissions supporting the sustainable use of living marine resources and promoting environmental conservation in marine areas. These include, *inter alia*, IWC (international Whaling Commission), CCAMLR (Commission for the Conservation of Antarctic Marine Living Resources), ICES (International Council for the Exploration of the Sea), IOC (Intergovernmental Oceanographic Commission of UNESCO), ICCAT (International Commission for the Conservation of Atlantic Tuna) and ISOM (International Ships Operators' Meeting). At national level, M&CM has provided advice to delegations at the CSD (Council on Sustainable Development) and the CBD (Convention on Biodiversity). Over the past year, it has also assumed responsibility for implementing relevant sections of the UNCLOS (United Nations Law of the Seas) locally and for national acceptance of the UNIA (United Nations Implementing Agreement for the Provisions of UNCLOS Relating to the Conservation and Management of Straddling Fish Stock and Highly Migratory Fish Stocks, the FAO Compliance Agreement and the FAO Code of Conduct for Responsible Fisheries.)

In addition to the above, M&CM is playing a leading role at both national and international level in ongoing negotiations to formulate a management regime for the high seas areas of the South Atlantic (SEAFO – South East Atlantic Fisheries Organization). These negotiations are among the first to be undertaken under the UNIA and involve South Africa, Namibia, Angola and the United Kingdom (on behalf of its dependencies Ascension, St Helena and Tristan da Cunha) as Coastal States along with 10 other nations (including the European Union and the United States).

Both researchers and managers have taken a great interest in the multi-million Rand BENEFIT (Benguela Environment Fisheries Interaction and Training) programme. This is a regional initiative involving South Africa, Namibia and Angola, and over the past year its activities have begun to gain momentum. Key structures such as the Secretariat, Policy and Management Committees and Resources, Environmental and Training Working Groups have been established and most are now functioning effectively with active participation from South Africa as well regional and international partners (such as Norway, Germany and France). In respect of the Resources and Environment Working Groups, M&CM played a key role in the formulation of projects. The first set of pilot resource projects, which are linked to the Norwegian-funded Nansen Programme, have been approved and are currently being implemented. These include several research projects on hydroacoustics and gear performance (particular Norwegian strengths), hake, horse mackerel and Dentex (a small Angolan demersal species) as well as distributional and stock studies, including work on fish age determination. A workshop was held in Swakopmund in March 1999 to formulate a programme for the next five years. New projects were developed on horse mackerel and hake recruitment along with target strength, additional age determination studies and hake longline tagging.

On the environmental research front, some BENEFIT projects are being funded (to a level of about R1.4 million) by Germany. These include a process study in Namibia, ground-truthing ocean

colour, remote sensing and drifter studies and inshore monitoring. A further exciting and recent development has been the allocation of some R2 million by the African Development Bank for regional training cruises. Students for these cruises have been recruited from the entire SADC community and from as far afield as Kenya. F.R.S. Africana and F.R.S. Algoa have been used with the cruises providing both an opportunity for capacity building in the region as well for the study of interesting oceanographic features in the Benguela System.

ENVIFISH is a three-year European Union funded project involving six partners from Europe and four partners from the countries adjacent to the Benguela Current Upwelling Area (South Africa, Namibia and Angola). South Africa is represented by both the University of Cape Town and M&CM. The main objective of ENVIFISH is to develop appropriate methodologies for improving the sustainable management of small pelagic fish in the region. This will be done through studies focusing on the identification and quantification of key environmental variables that influence fluctuations in the recruitment and distribution of the main pelagic species in the Benguela and Angolan Systems. After the project was launched in Cape Town in October 1998, initial work has focused on the collation of fisheries data by the African coastal states and the provision of calibrated sea surface temperatures based on satellite images by the European Joint Research Centre for the period 1982–1997. Supporting studies are being undertaken by the other European partners. ENVIFISH requires that a largely common approach be followed in addressing the pelagic resources of the three African countries, facilitating cooperation and the sharing of experience. The accomplishment of specific tasks in given periods and allocation of funding are clearly defined, but the latter includes amounts for post-graduate student support. Liaison with other international and bilateral fisheries programmes in the region is an ongoing commitment.

VIBES is a collaborative effort involving M&CM, ORSTOM (Office de la Recheche d'Outre Mer) and the University of Cape Town. The main objective of the project is to study long-term changes in fisheries and pelagic fish recruitment, and their spatial patterns in relation to the environment. The first phase of the project (1997–1998) was successfully completed thanks to funding provided by the bilateral agreement between France and South Africa as well by ORSTOM directly.

VIBES has three main thrusts – modelling of the West Coast environment, retrospective analyses of existing data time-series for physical, biological and fisheries data, and the development of fisheries Geographical Information System (GIS). Good progress has been made on all three components and apart from bringing together local and French experts, VIBES has recruited PhD and Masters students from local and overseas institutions. To facilitate collaboration, several top French scientists have been seconded to the University of Cape Town and M&CM for the full duration of the project. Funding has just been received for the second phase (1999–2000) of VIBES. Following restructuring into the Institut de Recherche pour le Developpement, ORSTROM has indicated its commitment to both VIBES and to future cooperation with M&CM and the University of Cape Town after theproject is completed.

Although South Africa has several bilateral agreements in the sphere of marine fisheries, two are worthy of mention here as being fairly active on the research sphere. With Norway (other than through the regional BENEFIT programme), there has been research collaboration in acoustic and behavioural studies, in gear technology and ecosystem analysis. However, a major step forward was taken with the sponsorship by Norway of the advanced training of four young South African fisheries scientists in fisheries management at the University of Bergen. These four are working closely with and being supervised by local scientists on their coursework prior to their finalization of their M.Phil. in the year 2000.

The bilateral with the United States (the BNC) has focused largely on developing a collabora-

tive education initiative wherein educational establishments in both countries and State institutions such as M&CM will combine to improve capacity in marine science and fisheries administration available specifically, but not only, in South Africa. There has been other research collaboration, but mainly in research disciplines in which interaction took place a year or so ago.

Effective international cooperation was also carried out in a number of other technical areas. At a formal level, bilateral agreements have been signed to cover the exchange of scientific observers under the International CCAMLR Scientific Observer Scheme. Under this Scheme, South African observers have served with distinction on Australian, British, Japanese and New Zealand Patagonian Toothfish vessels. National scientific observers have also served on Japanese, Russian, Ukrainian and Taiwanese vessels in local waters under similar arrangements with those nations.

As already emphasized, such international collaboration is not only cost-effective in terms of exchanging ship's time or by providing berths for foreign scientists, it also offers opportunities for M&CM's scientists to broaden their experience and work in remote areas.

The above examples serve to highlight M&CM's growing involvement in international collaborative marine research and management. Many of the publications listed below attest further to our international alliances. To a large measure, such alliances are a consequence of an enviable reputation which has been earned by a dedicated core of M&CM scientists over many years.

ICES Symposium, November 1998, Cape Town

The International Council for the Exploration of the Sea, ICES, the body tasked with supplying management advice on the fisheries of the North Atlantic, held a symposium in Cape Town during November 1998. The symposium "Confronting Uncertainty in the Evaluation and Implementation of Fisheries-Management Systems" was jointly organised by ICES, M&CM and UCT. The symposium dealt with a very topical subject and was well attended by both scientists and managers. It was successful, was attended by 159 delegates from 25 countries, including delegates from 10 non-ICES countries and 28 papers have been accepted for publication.

Why was a North Atlantic fisheries organisation holding a symposium in South Africa? This was, in fact, the first ICES meeting held in the southern hemisphere. The reason was twofold: much of the expertise in the "operational-management-procedure-type" of approach to fisheries management is in South Africa and Australasia, and South Africa is conveniently situated for easy access to delegates from Europe and North America and from Australasia.

Comprehensive assessments of fish resources that really address the problems of uncertainty require a lot of time and highly trained individuals. ICES working groups perform annual assessments on about 150 stocks. They do not have the resources to do comprehensive assessments on every stock, and consequently the annual assessments are limited and lack consistency. An alternative approach is to do a comprehensive assessment, fully accounting for uncertainty and risk, on each stock every few (say five) years. A management plan is then implemented for the next five years, i.e. until the next comprehensive assessment. This approach allows enough time for the effects of the management plan to become visible and permits a critical evaluation of the performance of the management plan. It also makes optimum use of the skilled manpower necessary to undertake the assessments.

There is some pressure within the ICES community to move away from annual assessments to a longer-term "operational-management-procedure-type" of approach to fisheries management. South Africa and Australia are the only countries currently using the approach successfully, though others are looking at the idea carefully.

PUBLICATIONS

In 1998 Marine and Coastal Management (MCM) research personnel were involved in 139 publications, oral papers and poster presentations, 15 more than the previous year. Staff contributed to 75 refereed papers. This exceeds the non-refereed works by 13 items and represents a considerable increase over the past two years (36 in 1996 and 58 in 1997). Two symposia proceedings volumes of the *South African Journal of Marine Science* were published in 1998. Volume 19: *Benguela Dynamics. Impacts of Variability on Shelf-Sea Environments and their Living Resources*. Pillar, S. C., Moloney, C. L., Payne, A. I. L. and F. A. Shillington (Eds), contained 39 papers, 24 of which involved in-house personnel. Volume 20: *Cephalopod Biodiversity, Ecology and Evolution*. Payne, A. I. L., Lipiński, M. R., Clarke, M. R. and M. A. C. Roeleveld (Eds), contained 47 papers presented at the Cephalopod International Advisory Council' 97 symposium. These two international symposia proceedings contained 58 publications from non-MCM staff, involving mainly overseas scientists.

Publications involving staff, directly contracted staff and seconded staff

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